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THE ABSORPTION OF LIGHT AS A DETERMINING FACTOR IN THE SELECTION OF THE SIZE OF THE OBJECTIVE FOR THE GREAT REFRACTOR OF THE POTSDAM OBSERVATORY.[1]

By H. C. Vogel.

The extraordinary advances which technical science has recently made in the manufacture of glass for optical instruments, and especially for telescope objectives, extend not only to the production of very large and pure pieces for the latter purpose, but to the production of highly refrangible glass as free as possible from color.

At the technical laboratory at Jena varieties of glass have also been made, by the combination of which the secondary spectrum has been reduced to an almost imperceptible quantity, so that achromatic objectives of almost ideal perfection have actually been made and have come into use; but although the efforts which only two decades ago appeared to be hopeless—to produce kinds of glass which could be so combined—have thus been crowned with success, it was only too soon apparent that the kinds of glass used were not permanent when exposed to the air, as they soon became covered with an opaque film

[1] "Die Lichtabsorption als maasgebender Factor bei der Wahl der Dimension des Objectivs für den grossen Refractor des Potsdamer Observatoriums," *Sitz. d. K. Akad. d. W. Berlin* **46**, 1219–1231, 1896.

which made the objective unserviceable. At present, therefore, progress in the direction of object glasses for large telescopes has extended only so far as this, that glass of admirable purity and of almost complete freedom from color is available for their manufacture.

Lenses as free as possible from color are especially desirable when the telescope is to be used, not only for direct observations, in which case the less refrangible rays are those chiefly concerned, but also for photographic purposes. For the otherwise excellent, but strongly yellow glass used by Fraunhofer, the limit, up to which an increase of the diameter of a photographic objective is profitable (a consequence of the increased absorption as the thickness is increased), is reached at a diameter of about 35^{cm} to 40^{cm}; whereas, in the case of the more recent kinds of glass, this limit is approached only at a diameter about three times as great.

Various factors existed for determining the construction of the large refractor designed for the Potsdam Observatory and for fixing the size of the objective. Although the situation of the Observatory, so far as the atmosphere is concerned, may be regarded as a favorable one for Central Germany, it nevertheless cannot be compared with that of observatories located at greater elevations, as, for instance, the observatory on Mount Hamilton. A telescope with a visually achromatized objective of a size similar to that of the later American instruments could be but seldom used to advantage under the atmospheric conditions met with here, and only in exceptional cases could it furnish observations which would have equal weight with those of other and more advantageously located observatories. Aside from this, the chief purpose of the Observatory, in accordance with which its activities are restricted as closely as possible to the domain of astrophysics, was to be kept in view; especially to be considered was the construction of an instrument by means of which it would be possible to continue the investigation of the motions of the heavenly bodies in the line of sight — an investigation in which this Observatory took the first successful steps, and the methods

for observing which it has established. A favorable condition of the atmosphere, however, has not so important an influence on spectrographic as it has in general upon visual observations.

In the case of the recent large telescopes, for instance that of the observatory at Pulkowa and that of the Lick Observatory, the objectives of which are achromatized for the visual rays, the imperfect achromatism of the objective becomes disagreeably evident in spectroscopic investigations not limited to the visible part of the spectrum, inasmuch as only a small part of the more refrangible regions of the spectrum can be investigated at a time. The extent of the part which can be so investigated decreases as the dimensions of the instrument, and the separation of the focal points of the actinic rays, thereby determined, increase. I here briefly give a few figures taken from a previous investigation[1] of mine concerning the achromatism of the Potsdam refractor of $29^{cm}.8$ effective aperture, and of the Vienna refractor of $67^{cm}.5$ effective aperture,[2] in order that the reader may recall the magnitudes of the quantities here considered:

Potsdam Refractor		Vienna Refractor	
Wave-length $\mu\mu$	Distance of the focal point from λ 486 $\mu\mu$	Wave-length $\mu\mu$	Distance of the focal point from λ 486 $\mu\mu$
690	$+ 4^{mm}.2$	690	$+ 2^{mm}.1$
610	+ 0 .3	610	— 6 .7
530	— 1 .7	570	— 7 .8
470	+ 1 .6	470	+ 4 .4
430	+ 9 .2	430	+20 .7
410	+16 .7	410	+31 .1

Attempts to unite more accurately the actinic with the optical rays by inserting a correcting lens in the cone of light have, so far as my knowledge goes, led to no satisfactory results.

These experiences led quite naturally to the conclusion that the objective of the great refractor should be achromatized for the actinic rays. An advantage in the mechanical construction

[1] *Monatsber. d. K. Akad. d. W. Berlin*, 1880, p. 438.

[2] *Publ. d. Astrophys. Obs. zu Potsdam*, IV Bd., I Th., p. 54.

of the instrument and the dome was gained at the same time: that of obtaining with the same aperture a large reduction in the focal length of the objective and also a large reduction in the diameter of the dome. There existed, however, the necessity for providing the large instrument with a guiding telescope of the same focal length.

The intention at first was to devise an attachment for the large telescope (a system of lenses), by means of which a more complete union of the visual and actinic rays might be effected, and which might be thrown in or out at pleasure. However, since such a system, in order to be effective, would have to be composed of three lenses, and these, in order to obtain a fairly large field of view, could not be given a smaller diameter than 30^{cm} to 40^{cm}, various doubts arose as to the feasibility of the plan, having their origin partly in the not inconsiderable cost of the mechanical arrangement, as well as that of the lenses themselves. It was therefore decided to correct the large objective (achromatized for the chemically active rays) merely by means of a small double lens of Christie's construction, which should be introduced at a short distance from the focus when the large objective was required for spectroscopic investigations in the less refrangible parts of the spectrum, thus relinquishing any attempts to secure a considerable field of view. An experiment with such a correcting lens, which Steinheil of Munich computed and made for the photographically corrected refractor of 34^{cm} aperture and $3^{m}.4$ focal length, resulted quite satisfactorily.

Since for these reasons the great objective can be used to only a very limited extent for direct observation, the aperture of the guiding telescope was fixed at 50^{cm}, so that the guiding telescope itself must be regarded as a very effective instrument of observation; in fact, it exceeds in size all previously existing instruments in Germany.

In order to determine the size of the principal objective, a complete knowledge of the absorption of the kinds of glass to be used was especially necessary, since, as is well known, the absorption of the more refrangible rays, for which the objective

was to be achromatized, is greater than that of the less refrangible. The kinds of glass were, in accordance with the suggestion of Steinheil, who undertook the construction of the objective, ordinary light flint, O.340 (catalogue number of the technical laboratory at Jena), and ordinary silicate crown O.203, since these kinds of glass are easily obtained in large disks free from defects. No quantitative results as to the amount of absorption of these kinds of glass were at hand, and preliminary investigations were consequently undertaken at the Potsdam Observatory, with the result that 80^{cm} was adopted as the size of the objective. It is, therefore, larger than the objective of the Pulkowa Observatory, and will be the largest in Europe.

The great refractor of the Potsdam Observatory will accordingly consist of a double telescope, one tube having an objective of 80^{cm} aperture, achromatized for actinic rays, the other having an aperture of 50^{cm}, achromatized for visual rays. The focal lengths will be respectively 12^{m} and $12^{m}.5$, so that the ratio of the aperture to the focal length will be 1:15 for the principal instrument and 1:25 for the guiding telescope.

The investigations of the absorption of the kinds of glass decided upon for the objective were conducted chiefly by Professors Müller and Wilsing at this Observatory, and were concluded during the summer. Advantage was also taken of the opportunity to observe the effects of absorption of other kinds of glass, which are to be used for the spectrograph of the great refractor. Inasmuch as there are very few such determinations for new kinds of glass,[1] I believe that the publication of the following observations will be of somewhat wide interest, and that comparisons of different objectives given at the conclusion of this article will correct some erroneous notions which are frequently met with concerning the influence of absorption.

[1] I would here refer to: Conroy, "Some observations on the amount of the light reflected and transmitted by certain kinds of glass," *Phil. Trans.*, **180**, 245, 1889. Dr. Krüss, "Über den Lichtverlust in sogenannten durchsichtigen Körpern," *Abh. d. Naturwissensch. Vereins zu Hamburg*, Bd. XI, Hft. 1. Eder and Valenta, "Absorptionspectren von farblosen und gefärbten gläsern," *Denkschr. d. K. Akad. d. W. Wien*, Bd. LXI, 1894.

I. DETERMINATION OF THE ABSORPTION IN THE VISIBLE PART OF THE SPECTRUM BETWEEN $\lambda 677^{\mu\mu}$ AND $\lambda 436^{\mu\mu}$.

The following observations were conducted by Professor Müller, with a Glan's spectrophotometer[1] somewhat modified by myself. It need scarcely be mentioned that every precautionary measure was taken in the investigations, and that only a cylindrical beam, and no diffuse light, was sent through the glass plates. The figures (the mean of four settings) give the intensity of the light, after passing through the glass, in terms of the incident light. The computation of the effect of reflection was made for each kind of glass by means of Fresnel's formula, $I = 1 - \left(\frac{n-1}{n+1}\right)^2$, where n is the index of refraction. It was sufficient for the purpose to take for the index of refraction that of the mean wave-length of the part of the spectrum investigated, and n for b_1 ($\lambda 518^{\mu\mu}$) was therefore taken. The effect of multiple reflections within the parallel plane surfaces of the glass has been neglected as insignificant. The reduction of the absorption to a thickness of the glass $a = 100^{mm}$ is obtained from the formula, $I_1 = I_0 \, K^{\frac{a}{\beta}}$, in which K is the quantity of light after having passed through the absorbing medium of thickness β, in terms of the incident light.

Flint glass O.340
Thickness $= 148^{mm}$
n for $b_1 = 1.5835$

λ	Measurements				Without reflection	For thickness of glass 100mm
	Series I	Series II	Series III	Mean		
677	0.744	0.858	0.862	0.821	0.912	0.939
580	0.719	0.783	0.726	0.743	0.825	0.878
535	0.667	0.880	0.793	0.780	0.866	0.907
503	0.804	0.735	0.697	0.745	0.827	0.880
477	0.819	0.715	0.705	0.746	0.828	0.880
455	0.652	0.705	0.711	0.689	0.765	0.834
436	0.492	0.493	0.542	0.509	0.565	0.680

[1] *Monatsber d. Akad.*, März 1877.

Flint glass O.102
Thickness = 100mm
n for $b_1 = 1.657$

λ	Measurements			Without reflection	For thickness of glass = 100mm
	Series I	Series II	Mean		
677	0.695	0.704	0.700	0.794	0.794
580	0.718	0.745	0.731	0.829	0.829
535	0.720	0.704	0.712	0.808	0.808
503	0.688	0.689	0.689	0.782	0.782
477	0.603	0.632	0.617	0.700	0.700
455	0.615	0.553	0.584	0.663	0.663
436	0.544	0.453	0.499	0.566	0.566

Flint glass O.93
Thickness = 114.8mm
n for $b_1 = 1.632$

λ	Measurements					Without reflection	For thickness of glass = 100mm
	Series I	Series II	Series III	Series IV	Mean		
677	0.878	0.771	0.910	0.763	0.830	0.935	0.943
580	0.777	0.818	0.824	0.741	0.790	0.890	0.903
535	0.699	0.777	0.743	0 844	0.766	0.863	0.879
503	0.818	0.693	0.736	0.786	0.758	0.854	0.871
477	0.724	0.824	0.744	0.852	0.786	0.885	0.899
455	0.707	0.737	0.669	0 668	0.695	0.783	0.807
436	0.584	0.551	0.564	0.713	0.603	0.679	0.714

Crown glass O.203
Thickness = 141.5mm
n for $b_1 = 1.521$

λ	Measurements			Without reflection	For thickness of glass = 100mm
	Series I	Series II	Mean		
677	0.848	0.738	0.793	0.865	0.903
580	0.730	0.778	0.754	0.823	0.872
535	0 770	0.804	0.787	0.859	0.898
503	0.784	0.723	0.754	0.823	0.872
477	0.706	0.773	0.740	0.807	0.860
445	0.666	0.723	0.695	0.758	0.822
436	0.701	0.650	0.676	0.738	0.806

Crown glass O.598
Thickness = 102^{mm}.5
n for b_1 = 1.519

λ	Measurements			Without reflection	For thickness of glass = 100 mm
	Series I	Series II	Mean		
677	0.824	0.747	0.786	0.857	0.860
580	0.768	0.723	0.746	0.814	0.818
535	0.810	0.634	0.722	0.787	0.792
503	0.720	0.694	0.707	0.771	0.776
477	0.701	0.704	0.702	0.766	0.771
455	0.721	0.681	0.701	0.765	0.770
436	0.832	0.623	0.727	0.793	0.797

Observations in the blue at λ 436$^{\mu\mu}$ were difficult with petroleum light on account of the feeble intensity of this part of the spectrum, and since my eye is very sensitive to the more refrangible rays of the spectrum, I have repeated these observations, and at the same time have also made a few observations in the brightest part of the spectrum. I give here the values obtained, which agree very well with those found by Professor Müller.

Flint glass O.340

λ	Measurements				Without reflection	For thickness of glass = 100^{mm}
	Series I	Series II	Series III	Mean		
580 } 535 }	0.770	0.708	....	0.739	0.821	0.875
436	0.567	0.494	0.552	0.538	0.597	0.706

Flint glass O.102

λ	Measurements			Without reflection	For thickness of glass = 100^{mm}
	Series I	Series II	Mean		
580 } 535 }	0.669	....	0.669	0.759	0.759
436	0.470	0.485	0.478	0.542	0.542

Common glass O.203

λ	Measurements			Without reflection	For thickness of glass = 100mm
	Series I	Series II	Mean		
580 } 535 }	0.734	....	0.734	0.801	0.855
436	0.648	0.606	0.627	0.684	0.765

Common glass O.598

λ	Measurements			Without reflection	For thickness of glass = 100mm
	Series I	Series II	Mean		
580 } 535 }	0.741	....	0.741	0.808	0 812
436	0.593	0.595	0.594	0 648	0.655

2. DETERMINATION OF THE ABSORPTION OF THE MORE REFRANGIBLE RAYS BETWEEN λ 434$^{\mu\mu}$ AND λ 375$^{\mu\mu}$.

Before entering upon the more special parts of the investigation I must state, with reference to the properties of glass in general, that the absorbing power does not increase uniformly with the decrease in the wave-length; that rather an approximately constant effect is to be observed over large sections of the spectrum, and that the increase of the absorption takes place *per saltum*, as in the vicinity of the Fraunhofer lines G and H. The sudden and total disappearance of light of a certain wave-length with a certain thickness of glass is thus explained. For example, light flint glass of 10^{cm} to 15^{cm} thickness cuts off all light whose wave-length is less than 376$^{\mu\mu}$. In the case of heavy flint O.102 a sudden and very marked decrease in the intensity of the transmitted light may be observed in the neighborhood of H. The spectrum may be followed a short distance beyond K, but it is excessively weak, and is then once more suddenly broken off. These observations agree with those of Eder and

Valenta,[1] who, with a thickness of glass of only 1^{cm} have been able to observe a similar, quite sudden falling off in intensity with most of the glasses investigated by them. Corresponding to the smaller thickness of glass, a total extinction of light did not occur until the point λ 330$^{\mu\mu}$ was reached.

It further appeared that flint O.340 of about 15^{cm} thickness produced two absorption bands. The middle of the one, a very weak and diffuse band, has a wave-length of 437$^{\mu\mu}$, the middle of the other, a more sharply defined and quite conspicuous band, has a wave-length of 418$^{\mu\mu}$.6. The width of the latter corresponds to a difference of wave-length equal to 3$^{\mu\mu}$.5. The second absorption band also appeared in the spectrum when the light was passed through a plate of crown glass O.203 of about 14^{cm} thickness, but it appeared to be less strong. The heavy flint O.102 gave no absorption bands.

The determination of the absorption for certain places in the more refrangible parts of the spectrum by means of photography was beset by great difficulties arising from the fact that, according to recent investigations in photographic processes where the darkening of the plate is produced, not by the light directly, but by a process of development, a great difference exists between the resulting degrees of darkening and the product of the time and intensity concerned in their production. With the same exposure the photographic darkening does not increase proportionally to the intensity, but more slowly, and the deviation from such a law is different for plates of different manufacture. In order to deduce the intensity from equal darkenings, the times of exposure being known, the departure from the law, $It=C$, must be especially obtained for each plate, which in practice leads to difficulties scarcely to be surmounted.

Professor Wilsing has attempted to overcome this difficulty by limiting himself to the comparison of intensities differing but little from one another with equal times of exposure, so

[1] "Absorptionsspectren von farblosen und gefärbten Gläsern," *Denkschr. d. K Akad. d. W. Wien*, Bd. LXI, 1894.

that the measurements are based on the axiom that equal intensities produce in the same time equal darkenings. By measurements with Nicol prisms the reduction of two intensities, differing by any desired amount, to the same intensity, was made in accordance with the principle of Zöllner's photometer, and the photometric determinations in the more refrangible part of the spectrum differ, therefore, from those made by spectrophotometric means in the less refrangible part, in this respect only,—that the plate sensitive to light takes the place of the eye.

A more detailed presentation of the method pursued and the precautionary measures taken in carrying out the observations will be given by Professor Wilsing in the *Astronomische Nachrichten*. I here limit myself to pointing out their principal features, merely adding thereto the remark, with reference to the practical carrying out of the work, that the photographs were taken on bromide of silver gelatine plates with a small spectrograph which is frequently used, in combination with the photographic refractor of the Observatory, for photographing star spectra. It was found that a difference of 5 per cent. in the intensity could be recognized.

The results of measurements given in the following table are arranged and reduced in the same way as those given on pages 80 and 81. For computing the loss by reflection the index for h (λ 410$^{\mu\mu}$) was taken.

Flint glass O.340
Thickness = 148^{mm}
n for h = 1.601

λ	Measurements	Without reflection	For thickness of glass = 100^{mm}
434	0.389	0.434	0.569
(419)	(0.240)	(0.268)	(0.411)
400	0.435	0.486	0.614
390	0.280	0.313	0.456
375	0.221	0.247	0.388

The figures enclosed in brackets refer to the absorption band.

Flint glass O.102
Thickness = 100^{mm}
n for h = 1.682

λ	Measurements	Without reflection	For thickness of glass = 100^{mm}
434	0.439	0.502	0.502
400	0.405	0.463	0.463
395	0.146	0.167	0.167
390	0.022	0.025	0.025

Crown O.203
Thickness = 141^{mm}.5
n for h = 1.532

λ	Measurements	Without reflection	For thickness of glass = 100^{mm}
434	0.515	0.564	0.667
(419)	(0.455)	(0.498)	(0 611)
400	0.546	0.598	0.695
390	0.426	0.466	0.583
375	0.426	0.466	0.583

The figures enclosed in brackets refer to the absorption bands.

I have attempted to determine the absorption effect of the glass for the more refrangible rays in another way,— by exposing sensitive paper (chloride of silver) to the sunlight both directly and after it had passed through the glass to be investigated, and then determining the degree of darkening by means of a scale which was produced by successive exposures to light. The comparison was made in yellow light, since it was not permissible to fix and tone the papers. Bunsen and Roscoe[1] have shown that, within very wide limits, equal products of intensity of light and time of exposure represent equal darkenings of chloride of silver paper. I had formerly used the method to advantage in determining the diminution of light from the center to the limb of the Sun's disk,[2] and I have now

[1] *Pogg. Ann.*, **117**, 529 *et seq.*
[2] *Berichte d. K. d. W.*, Leipzig, July 1872.

verified my conclusion that by making a suitable choice of the time of exposure it was possible to attain a quite high degree of sensitiveness and to recognize a difference of intensity as small as 5 per cent.

From a large number of observations, in which not only the absorbing effect of each of the glasses separately was determined, but also the absorption of the different glasses relatively to one another, I have deduced the following results, which relate to rays that affect chloride of silver paper, *i. e.*, rays of the spectrum extending from G into the ultra-violet and having a maximum effect between *h* and H.

Kinds of glass	*d*	I_1	I_2	I_2 for $d = 100^{mm}$
Flint O.340	148.0	0.346	0.386	0.526
Flint O.102	100.0	0.247	0.282	0.282
Flint O.93	114.8	0.270	0.306	0.356
Crown O.203	141.5	0.432	0.473	0.589
Crown O.598	102.5	0.547	0.610	0.604

Here *d* is the thickness of the glass in millimeters, I_1 the intensity, in terms of the incident light, of the light after having passed through a thickness of the glass plate equal to *d*, I_2 the intensity after allowing for the loss due to reflection, for the calculation of which, instead of the values for *n* which have been given, 1.654 is taken for Flint O.93 and 1.529 for Crown O.598.

In order to form an idea of the difference between the absorbing effect of the glass in visual observations and in photography, the preceding determinations of the absorption for certain definite kinds of rays must be combined, with reference to the power of the corresponding rays to affect respectively the eye and the photographic plate. For the less refrangible rays, which are chiefly concerned in direct observations, the mean may at once be taken of Professor Müller's observations combined with my own; since most of the observations are in the brightest part of the spectrum, and by forming the mean the distribution of light with reference to intensity is

sufficiently taken into account. For the two kinds of glass which are to be used for the objective, the following values were obtained for the intensity of the light after having passed through a thickness of 100^{mm}, in terms of the incident light:

0.84 for Flint O.340 and
0.85 for Crown O.203

In determining the absorption for the photographic rays I have assumed that the widespread bromide of silver gelatine plates are used. Their sensitiveness begins at F and extends far into the ultra-violet, and has a maximum between H_γ and H_δ. I take from the preceding investigations the following values from which to obtain a mean:

λ	Flint O.340	Crown O.203
$455^{\mu\mu}$	0.83	0.82
436	0.69	0.79
434	0.57	0.67
400	0.61	0.70
h — H	0.53	0.59
390	0.46	0.58
	Mean 0.615	Mean 0.692

Since the kinds of glass intended for the objectives of the Potsdam refractor are those which are generally preferred for large instruments, and the glass of the laboratory at Jena is coming into more extended use, the following table, which was computed on the basis of the values deduced above, will be of practical importance:

Thickness of objective in cm	Intensity of the transmitted in terms of the incident light			
	With allowance for absorption only		With allowance for absorption and reflection	
	Visual rays	Actinic rays	Visual rays	Actinic rays
4	0.93	0.84	0.77	0.69
6	0.90	0.77	0.75	0.63
8	0.87	0.71	0.72	0.58
10	0.84	0.65	0.70	0.53
12	0.82	0.60	0.67	0.49
14	0.79	0.55	0.65	0.45
16	0.76	0.50	0.63	0.41
18	0.74	0.46	0.61	0.38
20	0.71	0.43	0.59	0.35
22	0.69	0.39	0.57	0.32
24	0.67	0.36	0.55	0.29
26	0.65	0.33	0.53	0.27
28	0.62	0.30	0.52	0.25
30	0.60	0.28	0.50	0.23
32	0.58	0.25	0.48	0.21
34	0.56	0 23	0.47	0.19
36	0.55	0.21	0.45	0.18
38	0.53	0.20	0.44	0.16
40	0.51	0.18	0.42	0.15

The total thickness of the objective may, for the purpose of calculation, be taken at one-sixth or one-seventh of the diameter.

From the preceding table it follows that for the large objective of the new Potsdam refractor of 80^{cm} aperture, and of an assumed thickness of 12^{cm}, the loss of the actinic rays by absorption is approximately 40 per cent.; by both absorption and reflection 51 per cent. The ratio of the intensity of the transmitted light to that of the incident is 49 : 100.

To compare this with the objective of the Institute's photographic refractor of $34^{cm}.4$ aperture and 5^{cm} thickness, the ratio of the light-gathering power of the objectives is computed by multiplying the ratio of the squares of their apertures by the ratio of the amounts of transmitted light, expressed in terms of the same unit; that is $\frac{(80)^2}{(34.4)^2} \cdot \frac{49}{66} = 4$. The images of stars at the focus are therefore four times as bright for the

objective of 80^{cm} diameter as for the objective $34^{cm}.4$ in diameter, which corresponds to a gain of 1.5 stellar magnitude. A comparison with the Schröder refractor of the Observatory of $29^{cm}.8$ aperture, with which the determination of the motion of stars in the line of sight down to a magnitude of 2.5 was made, gives a much more favorable result. It may be assumed that with the objective of 80^{cm} aperture at least two additional magnitudes will be added to the range of observation. The number of stars whose motion can be investigated with the same precision as heretofore will be increased eightfold, or to about 400.

In spectroscopic investigations in the less refrangible part of the spectrum the intervention of a correcting lens becomes necessary, and this involves a still greater loss of light which can, however, scarcely be estimated at more than 20 per cent., since the compound lens will at most be about 20^{cm} in diameter and 4^{cm} thick, and the component lenses can be cemented together. Nevertheless, in consequence of the much smaller absorption for the optical rays, the gain of light of the large objective in comparison with that of the Schröder refractor will still be 1.8 magnitudes.

I may here also make a comparison in another direction, and will answer the question, "What advantage would be obtained by the use of a still larger objective, for instance one of 100^{cm} aperture?" If the thickness of the objective be taken as 15^{cm}, the result for the chemical rays is $\frac{100^2}{80^2} \cdot \frac{43}{49} = 1.43$, corresponding to a gain of 0.3 to 0.4 magnitude; a gain which is disproportionate to the very heavy cost of the objective and mountings.

Finally, I may give a comparison of the photographic refractor of $34^{cm}.4$ aperture, for which the ratio of aperture to focal length $= 1 : 10$, with the large objective of 80^{cm} aperture, with respect to the images which they form of objects that are not points. Here the ratio of aperture to focal length is chiefly concerned. Let V be this ratio, and let quantities relating to the large objective be represented by capitals, and those of

the small objective by small letters of the alphabet. Then

$$\frac{h}{H}=\frac{i}{I}\left(\frac{v}{V}\right)^2,$$

where I is the intensity of the transmitted light in terms of the same unit. The result is

$$\frac{h}{H}=\frac{66}{49}\cdot 1.5^2=3.$$

The brightness of the image per unit of surface for the smaller objective with relatively short focal length is therefore three times as great as for the large objective. The images in the focal plane of the latter have, however, twelve and one-half times as large an area.

THE SPECTRUM OF ζ PUPPIS.

By EDWARD C. PICKERING.

THE announcement was made in *Circular* No. 12 that the spectrum of the star ζ Puppis contained, in addition to the usual series of lines due to hydrogen, a second series of rhythmical lines. A remarkable relation exists between these two series, from which it appears that the second series, instead of being due to some unknown element as was at first supposed, is so closely allied to the hydrogen series, that it is probably due to that substance under conditions of temperature or pressure as yet unknown. The wave-lengths of the lines of hydrogen may be computed by the formula $\lambda = 3646.1 \frac{n^2}{n^2-16}$ which is the formula of Balmer, slightly modifying the constant term so that the standard wave-lengths of Rowland shall be represented, and substituting $\frac{1}{2}\, n$ for m. The wave-lengths of the lines of hydrogen may be determined by this formula if we substitute for n the even integers 6, 8, 10, 12, etc.

In the annexed table the values of n, the designations of the corresponding lines of hydrogen, their computed wave-lengths, their observed wave-lengths, and the observed minus the computed values are given in the first five columns. If now we substitute for n the odd integers 5, 7, 9, 11, etc., we obtain the wave-lengths of the second series of lines in the spectrum of ζ Puppis, as is shown in the second part of the table. The sixth column gives the value of n, the seventh the corresponding computed wave-length, and the eighth and ninth the wave-lengths of the lines in ζ Puppis as derived from two series of measures. Miss A. J. Cannon has found that the same series of lines occurs in the star 29 Canis Majoris (*H. P.* 1380) whose position for 1900 is R. A.$=7^h\ 14^m.5$, Dec. $=-24^\circ\ 23'$. As this star has the magnitude 4.8, only three lines of the series are measurable in the photographs so far taken, but, unlike ζ Puppis,

many additional lines are present. Measures of the lines common to ζ Puppis are given in the tenth column of the table and the observed minus the computed values for the two stars are given in the last three columns.

n	Des.	Comp.	H	O—C
4	--	∞	—	....
6	*Hα*	6563.0	6563.0	0.0
8	*Hβ*	4861.5	4861.5	0.0
10	*Hγ*	4340.6	4340.7	— 0.1
12	*Hδ*	4101.9	4101.8	+ 0.1
14	*Hε*	3970.2	3970.2	0.0
16	*Hζ*	3889.2	3889.1	+ 0.1
18	*Hη*	3835.5	3835.5	0.0
20	*Hθ*	3798.0	3798.1	— 0.1

n	Comp.	ζ	ζ	29	ζ	ζ	29
5	10128.1	.....	.....	.....	.....	.....	.....
7	5413.9	.....	.....	.....	.....	.....	.....
9	4543.6	R	R	R	.....	.....	.....
11	4201.7	4199.2	4201.6	4201.1	— 2.5	— 0.1	— 0.6
13	4027.4	4027.1	4026.5	4025.4	— 0.3	— 0.9	— 2.0
15	3925.2	3924.6	3924.9	.....	— 0.6	— 0.3	.....
17	3859.8	3858.7	3858.6	.....	— 1.1	— 1.2	.....
19	3815.2	3814.7	3817.2	.....	— 0.5	+ 2.0	.....
21	3783.4	.....	3783.4	.....	.....	0.0	.....

The wave-lengths here given depend upon the lines of hydrogen and were determined from them by a form of graphical interpolation. The interval between *Hβ* and *Hγ* is so great that the errors of interpolation are large for lines in that part of the spectrum. These errors are still greater in the approximate measures given in *Circular* No. 12, although the results there given for the five lines of the series of shorter wave-length than *Hγ* agree closely with those given above. Comparing the spectrum of ζ Puppis with the spectra of other stars, it appears that the four lines between *Hγ* and *Hβ* probably coincide with the lines having wave-lengths 4472, 4544, 4633, and 4688. The first of these lines is very faint and appears to coincide with the

principal line distinguishing stars of the Orion type. The second line is well marked and is the line computed above when $n=9$. The third and fourth lines are bright and coincide with the principal lines in spectra of stars of the fifth type. These four lines are also present in 29 Canis Majoris. Several of the lines in the above table appear bright in stars of the fifth type. Thus in *H. P.* 1311 the lines for which n equals 8, 9, 10, 11, 12, 13, and 14 are bright. In γ Velorum these lines are also present, some being bright and some dark. The line for which $n=7$ is one of the most conspicuous in the visual spectra of stars of the fifth type. Its wave-length has been found by Campbell to be 5412.4, which agrees closely with the computed value 5413.9. He also finds the line 4540, which is probably identical with the line for which $n=9$. From photographs recently taken at Arequipa, but not yet received at Cambridge, it is expected that the wave-lengths of all these lines can be accurately determined.

January 12, 1897.

ON THE SPECTRUM OF ζ PUPPIS.

By H. KAYSER.

THE Harvard College Observatory *Circular* No. 12 contains a very interesting notice by Professor Pickering on the spectrum of ζ Puppis. Besides some bright lines it shows the hydrogen series and a series of lines hitherto unknown with the wave-lengths 3814, 3857, 3923, 4028, 4203, 4505. I think this series is of the highest interest, because it seems probable to me that we have here another hydrogen series. That the lines form a series was remarked also by Professor Pickering, and he finds that they are represented approximately by the modified formula of Balmer: $\lambda = 4650 \frac{m^2}{m^2 - 4} - 1032$, where m has the value 5 for the last observed line.

After seeing Professor Pickering's *Circular*, I immediately calculated the reciprocals of the wave-lengths and their differences. With the aid of the table given by Kayser and Runge ("Ueber die Spectren der Elemente," *Abhand. d. K. Akad. d. W. Berlin*, 1891, p. 65) it became evident that the last line must really have the number 5, so that it corresponds to the hydrogen line 4342. In plotting on the scale of frequencies the spectrum of hydrogen and the new lines of ζ Puppis, it appears that the lines of the two series lie nearer and nearer together as the order of the lines gets higher. It therefore seems that the ends of the two series would nearly coincide. Now Runge and myself have found that in the spectra of all the elements, where series could be found at all, there were two series ending at nearly the same place. In our formula $\frac{1}{\lambda} = A - Bm^{-2} - Cm^{-4}$ this is expressed by the fact that for the two series of every element A has nearly the same value. Besides these two series the alkalies have a third series, named by us the principal series, the lines of which are situated high in the ultrale-viot compared

with the other two series. Hydrogen has been so far the only element with a single series, and as the principal series contains the most intense lines of every element, it was generally thought that the hydrogen lines were the principal series. But I was never convinced of it: as with decreasing atomic weight all the series recede to shorter wave-lengths, and as the principal series of lithium ends below λ 2300, one would expect to find the principal series of hydrogen in parts of the spectrum hitherto photographed only by Schumann. But if the known series were not the principal series, we should expect to find another series ending at nearly the same point, with lines a little less intense but sharper. Now these conditions are fulfilled by the new series. Professor Pickering's photograph shows very well that every new line is weaker and sharper than the corresponding hydrogen line. The old hydrogen series is represented by the formula $\frac{1}{\lambda} = 27430 - 109721\, m^{-2}$, the new series by the approximate formula $\frac{1}{\lambda} = 27559 - 134054\, m^{-2}$. (I have calculated the constants only by the first and last lines; the method of least squares would, of course, give a closer approximation.) For the two series of lithium the corresponding constants are 28587, 109625, and 28667, 122391. I think this comparison shows that it is not improbable that Professor Pickering has found a new series of hydrogen, not the indication of a new element.

That this series has never been observed before, can perhaps be explained by insufficient temperature in our Geissler tubes and most of the stars.

BONN, Jan. 2, 1897.

ON THE SPECTRA OF HEAVY AND LIGHT HELIUM.

By J. S. AMES and W. J. HUMPHREYS.

SOON after helium was discovered by Professor Ramsay, it was suspected by several spectroscopists that the gas discovered was not pure, but a mixture. Crookes and Lockyer, both, based their opinions on observed irregular changes in the spectrum, but Runge and Paschen, as the result of a most interesting research, brought forward evidence which seemed quite conclusive in favor of the belief that the new gas derived from clèveite was a mixture of two "elementary" gases. It had been shown by Kayser and Runge that in the spectra of many elements there were three series of lines, each series having definite characteristics; and, so, when Runge and Paschen showed by a most elaborate investigation that in the spectrum of cléveite gas there were two independent sets of series, each set including the three characteristic and well-known series, strong evidence was afforded in favor of two elements being present in clèveite gas. Other evidence was also given, partly spectroscopic, partly chemical. One set of series of lines appears much more frequently in the chromosphere of the Sun than does the other; again, after diffusion through a porous plug, one set of series was much weaker than in the natural gas. More recently, in a paper by Ramsay and Collie, in the *Proc. R. Soc.*, **60**, 206, the authors show that by a process of diffusion, many times repeated, it is possible to separate helium gas into parts of widely different densities. In one experiment they obtained gases differing in density in the ratio of five to six.

With the spectroscope at their command, Ramsay and Collie were unable to detect any differences between the spectra of the heavy and the light helium; and it is through the kindness of Professor Ramsay that we have had placed at our disposal various specimens of heavy, light, and ordinary helium; so that their spectra might be studied by means of the instruments of

great dispersion in use in the physical laboratory of the Johns Hopkins University.

The tubes which we have examined are marked as follows:

1. Helium and argon.
2. He. II., Ap. 27, 95. W. R.
3. Samarskite, heaviest. Contains air.
4. Samarskite, lightest.
5. Residue from 400^{cc} He. from Samarskite, after at least ten diffusions.

In addition to these we have studied the spectra of two helium tubes which were filled by Professor Ramsay in previous years, and of a third belonging to Professor Remsen, which had been filled with helium, prepared from Samarskite by Professor E. C. Franklin, of the University of Kansas. The spectra were obtained by means of a concave grating, six inches wide, having 15,000 lines to the inch, and a radius of curvature of twelve feet. Both eye and photographic measurements were taken, the discharge was passed both with and without spark-gap, with both large and small current; and *in no case were there any differences observed between the spectra of the various tubes.* Most of the photographs were taken so as to include w.-l. 3600–5030; for in this space there are lines of all the six series observed by Runge and Paschen. The character of the lines, the relative intensities, and the entire appearance of the spectra are in all cases the same, so far as we can judge. It seemed at first as if the helium line, principal series, 3888.785, was different on various plates; but the differences observed proved to be due not to the line itself but to lines exceedingly close to it. It is possible that the difference between heavy and light helium is due to the presence of an impurity, which, although occurring in varying amounts, may still give rise to a strong spectrum.

JOHNS HOPKINS UNIVERSITY,
December 1896.

OXYGEN IN THE SUN.

By Lewis E. Jewell.

In the Astrophysical Journal for December is a short paper by C. Runge and F. Paschen, in which they conclude that probably three lines in the solar spectrum at λ 7772.20, 7774.43, and 7775.62 (Higgs' map) coincide in position with three lines of oxygen produced in the vacuum tube under certain conditions. Mr. McClean had examined the lines upon photographic plates and had concluded that the three lines in question were probably produced in the Sun's atmosphere and not in that of the Earth.

I have examined these lines, using the large plane grating spectrometer at the Johns Hopkins University. The grating is five inches wide and has 15,000 lines to the inch. It is one of the finest gratings ever ruled and wonderfully bright in the red; when it was new I observed lines below λ 8600 in the infra-red. Observations were made on December 23, 24, 25, 27, and 31, 1896 and on January 4, 1897.

On December 31 and January 4 the air was warm and very humid, while upon the other days it was dry and cold.

Some attempts were made to see what effect the Sun's rotation produced upon these lines; but the spectrum is exceedingly weak to the eye when the slit of the spectroscope is placed near the edge of the Sun's disk, so that no satisfactory observations of this character have yet been made. Other observations, however, were so decisive in their character that confirmation by this method is not necessary.

At noon of December 24 with the Sun at an altitude of 27°, the lines at λ 7772.20 and 7774.43 (the strongest lines of the supposed oxygen triplet) were weaker than the lines in the 15th pair in the tail of A (due to atmospheric oxygen). Near sunset, when the Sun's altitude was about 4°, the lines in question were stronger than those of the 14th pair of A. The sunlight at

the last observation passed through five times as much atmosphere as during the former observation, and the lines of atmospheric oxygen had correspondingly increased in intensity. As these comparisons show that the suspected lines had increased much more in intensity than those of atmospheric oxygen used for comparison, it was evident that the suspected lines were unquestionably produced in the Earth's atmosphere but could not be due to atmospheric oxygen. Comparisons were also made with the solar line at λ 7699.1; and, while the suspected lines was *very much* weaker than the solar line at noon, near sunset they were stronger.

Observations were made under similar conditions on December 25 and 27, and the previous results confirmed.

On December 31 the air was warm and very moist. With the Sun at an altitude of 27°, the lines were weaker than those of the 14th pair of A and stronger than those of the 15th pair, being nearer the 14th. Observations made during both the morning and afternoon, when the Sun's altitude was about 15°, showed the lines to be slightly stronger than those of the 13th pair of A. (These results were confirmed by observations of Dr. J. S. Ames.) Observations made later in the afternoon showed that the lines were becoming relatively stronger; but the air was getting hazy and the spectrum weak; so that no reliable estimates could be made, though the lines could be seen until the Sun was about 5° from the horizon.

On January 4, an observation was made with the Sun at an altitude of 27° 30′, and the lines in question were stronger than those of the 14th pair of A but weaker than those of the 13th pair. Observations upon known water-vapor lines showed the humidity of the air to be greater than upon December 31. Clouds however prevented any further observations; but those already made prove conclusively that the three lines supposed to be due to oxygen in the Sun are produced by water vapor in the Earth's atmosphere.

JOHNS HOPKINS UNIVERSITY,
January 4, 1897.

ON THE EFFECT OF PRESSURE IN THE SURROUNDING GAS ON THE TEMPERATURE OF THE CRATER OF AN ELECTRIC ARC. CORRECTION OF RESULTS IN FORMER PAPER.[1]

By W. E. WILSON and G. F. FITZGERALD.

IN May 1895 a preliminary paper by one of the authors was read at the Royal Society, in which is described the apparatus used for these experiments, and the results which were then obtained.

The primary object of this research was to determine, if possible, whether the temperature of the crater in the positive carbon varies when the pressure in the surrounding gas is changed.

It has been suggested that the temperature of the crater is that of boiling carbon. The most modern determinations give this temperature of the crater as about 3300°–3500° C.[2]

If this is the true boiling point of carbon, it is then clear that solar physicists must find some other substance than solid carbon particles to form the photospheric clouds in the Sun, as the temperature of this layer is most probably not below 8000° C.,[3] unless, indeed, the pressure in the solar atmosphere is sufficient to raise the boiling point of carbon to about this temperature. It is in order to throw some light on this subject that these experiments were undertaken.

The gas used in our first experiments was nitrogen, and we found that the radiation from the crater fell off in a most remarkable manner whenever the pressure was raised in the box surrounding the arc. This falling off was not due to any very large extent to visible cloud or smoke, and the crater seemed so much reduced in temperature as to glow with only a red heat. This seemed to show that the temperature of the crater depends

[1] Read before the Royal Society.

[2] WILSON and GRAY, *Proc. R. Soc.*, **58**; Violle, *Jour. de Phys.*, 3d series, **2**, 545.

[3] WILSON and GRAY, *Phil. Trans.*, A, **185**, 1894.

on how much it is cooled by the surrounding gas, and not on its being the temperature at which the vapor of carbon has the same pressure as the surrounding atmosphere.

It was found that we were limited to pressures not exceeding about 20 atmospheres, as at this pressure we could not withdraw the negative carbon sufficiently to see into the crater without the arc breaking. We were then only able to obtain a current from a battery of accumulators which had an E.M.F. of 110 volts. Since then we obtained a Crompton dynamo which could give 300 volts and 15 amperes, and which was driven by a turbine.

From the great difficulty of obtaining a sufficient quantity of pure nitrogen under pressure, we obtained a 20-foot cylinder of air compressed to 120 atmospheres. With this we tried a series of experiments, and these at first seemed to corroborate our former ones, in which we used nitrogen, but we found that at any rate some of the radiation, and possibly a great deal of it, was cut off by the formation of what appeared to be red fumes of NO_2. We found no absorption from this cause so long as the pressure was nearly atmospheric, but at about 100 pounds pressure this gas was formed with great rapidity, and undoubtedly cut off a great deal of the radiation. We easily confirmed our belief in the presence of this gas by its well-known absorption spectrum.

Lest heat dissociation might cause an apparent increase in the amount of NO_2, we tried heating some of this gas in a flask. We observed that when hot the brown fumes became golden yellow, and the absorption bands nearly disappeared, so that the heating could *not* have been the cause of the apparently enormous production of NO_2 at high pressure.

We next tried whether oxygen blown into the arc would burn up the carbons, but found it did not do so to any serious extent, and so tried the arc in a compressed atmosphere of this gas.

The arc burned very nicely indeed in the oxygen, the carbons keeping a good shape and a very steady crater. The oxy-

gen was, however, so contaminated with nitrogen that at high pressure enormous quantities of NO_2 were again formed, so that we could not proceed further with the radiation experiments. The arc was a bright blue bead, about the size of a pea, and the spectrum was a beautiful banded one.

From these results we concluded that the reduction of radiation and red-hot appearance of the crater in the former experiments in nitrogen were due to its being contaminated with oxygen, and to the large quantities of NO_2 which were formed by the arc when under pressure.

We next tried the arc in hydrogen. The gas was obtained as pure, but contained hydrocarbons as an impurity, possibly from having been compressed into a cylinder which had previously been charged with coal-gas.

The arc in hydrogen at atmospheric pressures was a long, thin flame, that moved as far up the carbons as possible; especially on the negative carbon it walked up a centimeter along the cone. It went so far that it fused the copper ring that held the negative carbon, and we had to replace it by an iron wire lashing. It was very unsteady, and trees of soot and a deposit of hard graphitic carbon formed on this positive carbon as if there were electrolysis of the hydrocarbon, and carbon were electro-negative compared with hydrogen. This growth took place all round the crater, while there was no tendency for anything to grow on the negative carbon.

The arc was only 5–6^{mm} wide, and sometimes over 2^{cm} long. There was a green outer flame, with a bright red line not 1^{mm} wide down the middle of it. Where it impinged on the negative carbon there was a bright red flame from the middle of the bright spot on the carbon. The outer greenish part seemed to give much the same spectrum as the green cone in a Bunsen burner, while the red flame and line was undoubtedly glowing hydrogen. As we saw the C and F hydrogen lines very distinctly, the red C line being dazzlingly bright and not nearly so wide as in a coil spark at atmospheric pressure whenever the image of the red part of the arc was thrown on the slit of the

spectroscope, the appearance was quite like that of a solar prominence.

The end of the positive carbon was pitted into a number of craters, as the arc was very unsteady, and when the pressure was raised it was almost impossible to keep an arc going, partly because the arc broke when it was elongated the least bit, and partly because a complete lantern of soot trees grew all round the crater, and seemed to short circuit the arc from time to time.

The arc being very unsteady, no satisfactory reading of the voltage and current was possible. At from 60 to 80 pounds pressure the voltage varied from 60–80, and the amperes kept continually varying from 15–20. At 40 pounds with 20 amperes the volts varied from 50–60. The crater was not well developed, so that the radiation observation, even at low pressures, was not very satisfactory, while at high pressures the arc was too short to see into the crater at all, and the lantern of soot trees hid a considerable length, 3^{mm} or 4^{mm}, of the negative carbon besides. The radiomicrometer gave 440 divisions with a good arc in air, and 380 with the moderately good crater in hydrogen. But this difference is no greater than would often occur with a good and moderately good crater, so that there is not any proof of a difference of temperature due to cooling power of hydrogen. These experiments showed us that it was quite hopeless to get any measures of radiation under pressure with hydrogen.

We finally tried an atmosphere of carbon dioxide. We used a cylinder of liquid CO_2, which was connected to our arc box by a copper tube and stop valve. The arc burned fairly well in this gas, and, except for the difficulty of getting a sufficiently long arc at pressures above 150 pounds, some pretty satisfactory measures of radiation were obtained. We found that whenever the pressure was suddenly reduced there was a fog formed in the box, which cut off the light enormously. Also by looking down the steel tube, which is closed at its end by a lens, we could see powerful convection currents in the gas which scattered a lot of light. At high pressure the refraction due to these currents prevented any sort of an image of the crater being formed

while the pressure was varying. While the pressure was steady a good image could be formed. This tube is nearly 3 feet in length, and only one-half inch in bore, and it would naturally take time for the gas to settle down throughout its length. We propose to have this tube removed, and the aperture in the box closed by a strong piece of plane glass, and to form an image of the carbons by a lens placed at a suitable distance outside. This we expect will remove the difficulty arising from these convection currents.

The result of all these experiments so far is that it would require more evidence than we have been able to get to affirm that either the temperature of the crater of the arc is raised or lowered by pressure. We got some very concordant observations, which showed the temperature to be lowered with pressure, and in which at the time we could see no evidence of absorption by fog; but then, at other times, there was undoubtedly absorption from this cause. We certainly got no evidence that there is any appreciable increase of temperature. When the arc was started in the gas at a low pressure and then the pressure was raised, the radiation at the low pressure was greater than at high pressure; but when the arc was started first in the gas at high pressure, and then the pressure reduced, the radiation was rather higher in the gas at high pressure. From all this we concluded that the greater part of the differences we were observing were due to the absorption of the light in the long tube already mentioned, which increased the longer the arc was kept burning, and was probably greater at high than at low pressures. The best observations were made with variations of pressure from 15 up to 100 pounds per square inch, and there seems very little evidence of much change of radiation with this change of from 1 up to between 6 and 7 atmospheres.

The whole question is surrounded with great difficulty. If the carbon be really in equilibrium with its own vapor at the temperature of the crater and at the pressure of the surrounding atmosphere, some relation must exist between the change in pressure and change in temperature of the crater. If we knew

the latent heat of volatilization of carbon, we should be able to calculate the change of temperature from the well-known thermodynamic formula

$$\frac{\delta T}{T} = \frac{\Delta v}{\lambda} . \delta p.$$

Δv can certainly be approximately determined on the supposition that the absolute temperature of the crater is fifteen times the absolute temperature of the freezing point, *i. e.*, 3800°. We thus get for gaseous carbon $\Delta v = 10^4 qp$ at this temperature. For 1 atmosphere $\delta p = 10^6 qp$, so that

$$\frac{\delta T}{T} = \frac{10^{10}}{\lambda} .$$

Hence, unless the latent heat of carbon be enormously great compared with that of other substances, δT / T will be considerable. If λ be as great as the latent heat of vaporization of carbon given by Trouton's law, *i. e.*, about 4000 calories, or 16.8×10^{10} ergs, δT / T will be about $\frac{1}{17}$, and δT will be nearly 220°C. for each atmosphere, and a change of pressure of about 18 atmospheres would raise the temperature of the crater to that estimated for the Sun. The corresponding increase of radiation would be very great, for the radiation varies, at least approximately, as the fourth power of the absolute temperature. This would lead one to expect that the radiation would be nearly doubled for each 4 atmospheres added. Such an increase as this certainly does not take place, so that we may conclude that either the temperature of the crater is not that of boiling carbon, or else that the latent heat of volatilization of carbon is very considerably greater than that calculated from Trouton's law. Even though this latent heat were as great as the heat of combustion of C to CO_2, *i. e.*, 7770°, there would be an increase of about 70 per cent. in the radiation for an increased pressure of 6 atmospheres. Such an enormous latent heat is unprecedented, and yet our experiments would almost certainly have shown such an increased radiation as this. So far, therefore, the experiments throw considerable doubt on the probability that it is the boiling point of carbon that determines the temperature of the crater. It might be

questioned whether there is energy enough in the current to do all this work, but upon an extravagant estimate of the amount of carbon volatilized in the crater, it appears that there is more than a hundred times as much energy supplied by the current as would be required for volatilizing the carbon, even though its latent heat were as great as the heat of combustion of C into CO_2.

There is another considerable difficulty in the theory of the temperature of the crater being that of boiling carbon arising from the slowness of evaporation. The crater on mercury is dark, but then it volatilizes with immense rapidity and the supply of energy by the current being more than 100 times that required merely for evaporation, there seems very little reason why even a considerable difference in latent heat should make any sensible difference in the rate of evaporation of mercury and carbon, especially as, at the same temperature, the diffusion of carbon vapor is nearly three times as fast as that of mercury vapor and the temperature immensely higher.

We would, in conclusion, call attention to a cause of opacity in the solar atmosphere that is illustrated by the effect of convection currents in the long tube we were observing at high pressures; these convection currents behaved just like snow, or any other finely divided transparent body immersed in another of different refractive index. Light trying to get through is reflected backwards and forwards in every direction, until most of it gets back by the way it came. The consequence was that even the electric arc light was unable to penetrate the tube at high pressure, when these convection currents were active. The only light that came out of the tube was the feeble light outside, which was returned to us by reflection at the surfaces of these convection currents. In a similar manner we conceive that any part of the solar atmosphere which is at a high pressure, and where convection currents, or currents of different kinds of materials, are active, would reflect back to the Sun any radiations coming from below, and reflect to us only the feeble radiations coming from interplanetary space. In his paper on "The Physical

Constitution of the Sun and Stars" (*Proc. R. Soc.*, No. 105, 1868), Dr. Stoney called attention to an action of this kind that might be due to clouds of transparent material, like clouds of water on the Earth, but in view of the high solar temperature it seems improbable that any body, except perhaps carbon, could exist in any condition other than the gaseous state in the solar atmosphere; so that it seems more probable that Sun-spots are due, at least partly, to reflection by convection streams of gas, rather than by clouds of transparent solid or liquid particles.

PRELIMINARY TABLE OF SOLAR SPECTRUM WAVE-LENGTHS. XVII.

By HENRY A. ROWLAND.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3439 735		000 N	3444.217		0000
3439.841		0000	3444.402	Ni?	2
3439.941		0000	3444.467	Ti	4
3440.008	Fe	3	3444.590		0000 N
3440.138		000 N	3444.654		0
3440.235		00 N	3444.774		0000
3440.328		000 N	3444.847		00
3440.505		0 N	3445.030		000 Nd?
3440.635		000 N	3445.260	Fe	5
3440.762 s	Fe	20	3445.477		000 N
3440.875		00 N	3445.597		000 N
3441.021		000 N	3445.741	Fe, Cr	2 N
3441.155 s	Fe	15	3445.905	Fe	2
3441.248		000 N	3445.947		0000
3441.391		0 Nd?	3446.127		0000
3441.588	Cr	1 N	3446.240		1
3441.688	Pd	0000 N	3446.314		000
3441.808		0000 N	3446.406	Ni	15
3441.875		000	3446.536		1 Nd?
3442.035		0000	3446.620		0000 N
3442.118	Mn	6	3446.747		0000 N
3442.188	Ni	1	3446.857		000
3442.284		1	3446.931		00
3442.368		00	3447.089		0
3442.503	Fe	2	3447.154		00 N
3442.696	Ni	0	3447.290		0000 N
3442.813	Fe	3	3447.420	Fe, Co	4
3442.921		0000	3447.569	Cr	0
3443.059	Co	2	3447.674		0000 N
3443.101	Fe	1	3447.774		000
3443.181		00	3447.901	Cr	0
3443.330	Co	0	3448.040		0000 N
3443.435		000 N	3448.144		1
3443.517		1	3448.227		0000
3443.575		0000 N	3448.340		0 N d?
3443.691		0000	3448.494		000 N
3443.791	Co	5 d?	3448.597		000 N
3443.908		00 N	3448.727		000 N
3444.020 s	Fe	8 N	3448.827		0000 N
3444.127		0 N	3448.926		0

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3449.003		0	3455.736	Cr	0
3449.099		0000	3455.828		0000 N
3449.186		0000	3455.928		0000Nd?
3449.310	Co	5 d?	3456.081		0000
3449.446		0000	3456.148		00
3449.583	Co	6 d?	3456.228		000
3449.766		0000 N	3456.383	Fe	0
3449.833		0000 N	3456.528	Ti	3
3449.996		000 Nd?	3456.634		0000 N
3450.123		000 Nd?	3456.714		0000 N
3450.275		00	3456.801	Ti	00 N
3450.373		0000 N	3456.944		000 N
3450.469	Fe	5	3457.068	Co	1
3450.589		0000 N	3457.230	Fe	2
3450.742		0000 N	3457.281		00
3450.882		0000 N	3457.414		0000 N
3450.995		000 N	3457.538		0000 N
3451.129		0000	3457.648	Fe, Zr	0
3451.255		00	3457.708		0
3451.369		0000	3457.758		000
3451.477		0	3457.908		0000 N
3451.609	Mn	0	3458.028		0
3451.761	Fe	2	3458.144		000
3451.915		0000 N	3458.254		0
3452.057	Fe	3	3458.442	Fe	3
3452.419	Fe	4	3458.601	Ni	8
3452.609	Ti	1	3458.728		0 N
3452.762		000	3458.834		0 Nd?
3452.919		00 N	3459.074	Zr	00
3453.039	Ni	6 d?	3459.194		0000
3453.169	Fe	2	3459.288		000
3453.255		000	3459.414		000
3453.355	La	0000	3459.568	Fe	2
3453.469	Cr	0	3459.714		0000
3453.621	Co	3	3459.761		0000
3453.705		2	3459.881	Fe	1
3453.885		00	3460.052	Fe	3 d?
3453.982		0000 N	3460.174	Mn,-	2
3454.303	Ti	1	3460.294		0000
3454.455		00	3460.460	Mn,-	4 d?
3454.602		0000 N	3460.568	Cr	000
3454.725		000 N	3460.691		0000 N
3454.829		0000 N	3460.741		0000 N
3454.934		0000 N	3460.874	Pd	00
3455.058		0000	3461.021		000 N
3455.121	Mn	000	3461.111		00
3455.204	Mn	000	3461.321	Co, La	0
3455.379 S	Co	5	3461.413		0000 N
3455.494		0000 N	3461.633	Ti	5
3455.601		0000 N	3461.801	Ni	8

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3461.930		0 N	3468.612		0 N
3462.073		00 N	3468.821		1
3462.217		0000 Nd?	3468.986	Fe	2
3462.347		000	3469.114		0
3462.492	Fe	1	3469.155	Fe	2
3462.667		0000 Nd?	3469.532		0
3462.867		00 N	3469.628	Ni	3
3462.950	Co	6	3469.736	Cr	0
3463.153	Zr	0	3469.826		0000 N
3463.323		0000 N	3469.972	Fe	2
3463.444	Fe	1	3470.076		0000
3463.520		0000	3470.156		0000
3463.660		0000 N	3470.276		0000 N
3463.777		0000 Nd?	3470.380		000 N
3463.937		0000 Nd?	3470.536		00
3464.113		2	3470.678		0
3464.167		00	3470.776		0000
3464.275	Fe	1 d?	3470.876		00
3464.608 s		1	3471.000		0000
3464.843		000	3471.136		0000
3464.970		0000	3471.256		000
3465.052	Fe	0	3471.404	Fe, Zr	3
3465.167		0000	3471.499	Fe, Co	3
3465.300		0000	3471.598		0
3465.390	Cr	00	3471.750		000
3465.467		0000 N	3471.856		000
3465.573		0000 N	3471.910		0000
3465.687		1	3472.035		1 N
3465.779		1	3472.190		00 N
3465.900 } s	Co	4	3472.316		0 N
3466.015 }	Fe	6	3472.443		00 N
3466.137		00 N	3472.593		0
3466.187		00 N	3472.680	Ni	{ 5
3466.320		00	3472.730		{ 2
3466.420		0	3472.850		0000 N
3466.507		0000 N	3472.916		000
3466.639	Fe	3	3473.040		000
3466.773		0	3473.146		000
3466.853		0000	3473.190		0000
3467.033	Fe	2	3473.363		0000
3467.153		000 N	3473.435	Fe	2
3467.270		000 N	3473.637	Fe	1
3467.407	Ti	00	3473.756		0
3467.517		0000 N	3473.823	Fe	1
3467.644	Ni	3	3473.950		0000
3467.845	Ni, Cr	2	3474.106	Co	2
3468.007		000	3474.197	Mn	2
3468.210		00	3474.287	Mn	2
3468.347		0000 N	3474.410		0000
3468.486		0000 N	3474.523		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3474.576	Fe	2	3480.549		000
3474.669		00	3480.669	Ti	1
3474.800		000	3480.785		0000 N
3474.904		1	3480.875		0000 N
3475.023		00	3481.024	Ti	2
3475.143		0000 N	3481.195		00 N
3475.270		2	3481.302	Pd, Ti-Zr	2
3475.406		0	3481.439	Cr	0
3475.456		00	3481.589		0000
3475.594 s	Fe	10	3481.695	Fe, Cr	2
3475.656		0 N	3481.802		0000
3475.802	Fe	2	3481.889		000
3475.894		1	3481.952	Fe	00
3476.010	Fe	2	3482.075		000
3476.163		000 N	3482.195		000
3476.330		0000 N	3482.325	Fe	1
3476.479	Co, Fe	3	3482.589		000
3476 590		0000	3482.712		000 Nd?
3476.756		0	3482.855	Zr	00
3476.849 s	Fe	8	3483.047	Mn-	5 d?
3477.002	Fe	1	3483.155	Fe	4
3477.125	Fe, Ti	3 d?	3483.295		0000
3477.323	Ti	5	3483.553	Co	3
3477.500		000	3483.667	Fe, Zr	0
3477.636		00	3483.769		000
3477.770		0	3483.923	Ni	6 d?
3477.856		0000	3484.023		1
3478.002 s	Fe, Ni	4	3484.172		0000 N
3478.123		000	3484.295		3
3478.256		0000 N	3484.352		00
3478.316		0000 N	3484.482		000 Nd?
3478.438	Ni, Zr	0	3484.692		0000Nd?
3478.504	Fe	0	3484.809		0000 N
3478.689	Co, Zr	0	3484.922		00
3478.772	Fe	1	3484.995	Fe	1
3478.876		0000	3485.121	Fe	2
3478.923	Co	0	3485.249		1
3479.053		000	3485.369		0000 N
3479.163	Zr	0	3485.493	Fe Co	6
3479.273		0000	3485.645		0000 N
3479.401	Ni	1	3485.719		0000 N
3479.531	Zr	2	3485.845		00 N
3479.703		0000 N	3486.041 s	Ni	5
3479.829	Fe	1	3486.179		0000
3479.969		0	3486.282		0000
3480.061		1	3486.362		000
3480.171		00	3486.475		000
3480.315	Ni	1	3486.522		0000
3480.442		0000	3486.691	Fe	2
3480.476	Fe, Zr	2	3486.782		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3486.889		0000	3493.313		0 N
3486.962		0000	3493.430	Ti, Fe	1
3487.095	Mn	00 N	3493.618		2
3487.145		0000	3493.721		00
3487.289		0000	3493.834	Fe	1
3487.415		0000	3494.004		00
3487.542		000	3494.154		0000 N
3487.743		2	3494.308	Fe	2
3487.857	Co, Ca	0	3494.401		0000
3487.959		000	3494.498		0000
3488.131		2	3494.551		0000
3488.289		0c00 Nd?	3494.654		0
3488.437	Ni, Mn	0	3494.815	Fe	2
3488.589		000	3494.871		000
3488.702		0000 N	3494.994		0000 N
3488.817	Mn	4	3495.108	Cr	00
3488.965		1	3495.178		0000 N
3489.142		00 Nd?	3495.384		0
3489.302		00 N	3495.423	Fe	3
3489.392		0000 N	3495.522		2
3489.546	Co	5	3495.658		000
3489.813	Fe	3	3495.802	Co	3
3489.889	Ti, Pd	2	3495.853	Ti	2
3490.048		0000	3495.974	Mn	2
3490.104		0000	3496.024	Fe	2
3490.191		0000	3496.101		0000
3490.301		0	3496.224	Co	0
3490.341		0000	3496.348	Zr	2
3490.441		0000	3496.491	Ni	0
3490.534		00	3496.614		0000 N
3490.628		0	3496.721		0
3490.733 s	Fe	10 N	3496.820	Co	3
3490.896	Co	0	3496.952	Co, Mn	3
3491.008		000 Nd?	3497.148		1
3491.195	Ti	5	3497.241 } s	Fe	3
3491.354		000	3497.301 }		2
3491.462 s	Co,-	4	3497.421		0000 N
3491.661		0000 N	3497.534		0
3491.894		000	3497.668	Mn	3
3492.021		0000 N	3497.874		0 N
3492.112	Co	00	3497.982 s	Fe	8
3492.174		0000	3498.116		0
3492.284		0000	3498.322		1 N
3492.368		000 N	3498.451		0000 N
3492.508		00 N	3498.534		0000 N
3492.678		000 N	3498.668		00
3492.858		000 N	3498.888		1
3492.954		00 N	3499.084		00
3493.114	Ni	10 N	3499.248	Ti	0
3493.228		000 N	3499.408		00

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3499.492		0	3505.371		0000
3499.608		0000 N	3505.433		0
3499.711		0	3505.525		0000
3499.848		0000 Nd?	3505.628	Zr	0
3499.974		0000	3505.810	Zr-V	1
3500.013		0	3505.928		0000
3500.131		000	3506.038		0
3500.296		0	3506.189		000
3500.474	Ti	3	3506.380	Fe	1
3500.577		0000	3506.467	Co	5
3500.706 s	Fe	2	3506.645	Fe	3
3500.830		0000 N	3506.733	Ti	1
3500.996 s	Ni	6 d?	3506.793		0000
3501.094		0000	3506.891		0000
3501.210		0000	3506.980		0
3501.296		0000	3507.077		0000
3501.394		0000	3507.284		2
3501.472		000	3507.350		0
3501.605		000 N	3507.447		0000
3501.710		0000 N	3507.543	Fe	1
3501.841		0	3507.687		0000 N
3501.868		0	3507.837	Ni	3
3501.970		000 N	3507.957		000
3502.104		000 N	3508.090		00
3502.165		0000	3508.234		000
3502.394		{ 3	3508.350		1
3502.466	Co	{ 3	3508.487		0000 N
3502.608		00	3508.626	Fe	3
3502.737	Ni	2	3508.670	Fe	2
3502.775	Co	2	3508.847		0000 N
3502.899		0000	3509.037		00
3503.001		00	3509.157		0000
3503.112		0000	3509.264	Fe	2
3503.256		000 N	3509.470		0000
3503.442		000 N	3509.570		0000
3503.612		1	3509.690		0000
3503.699		0000	3509.870		1
3503.866	Co	00 Nt?	3509.992	Co, Fe	4
3504.048		00	3510.209		000
3504.192		0000	3510.331		1
3504.332		0000	3510.466	Ni	8
3504.399		0000	3510.596	Co, Fe	2
3504.581	Fe, V	2	3510.693		00
3504.733		0000	3510.824		1
3504.823		1	3510.985 s	Ti	5
3504.885	Co	0000	3511.209		0000Nd?
3505.015	Fe	3	3511.356		0000
3505.056	Ti	2	3511.453		0000
3505.202	Fe	3	3511.583		0000
3505.288	Co	0000	3511.676		0000

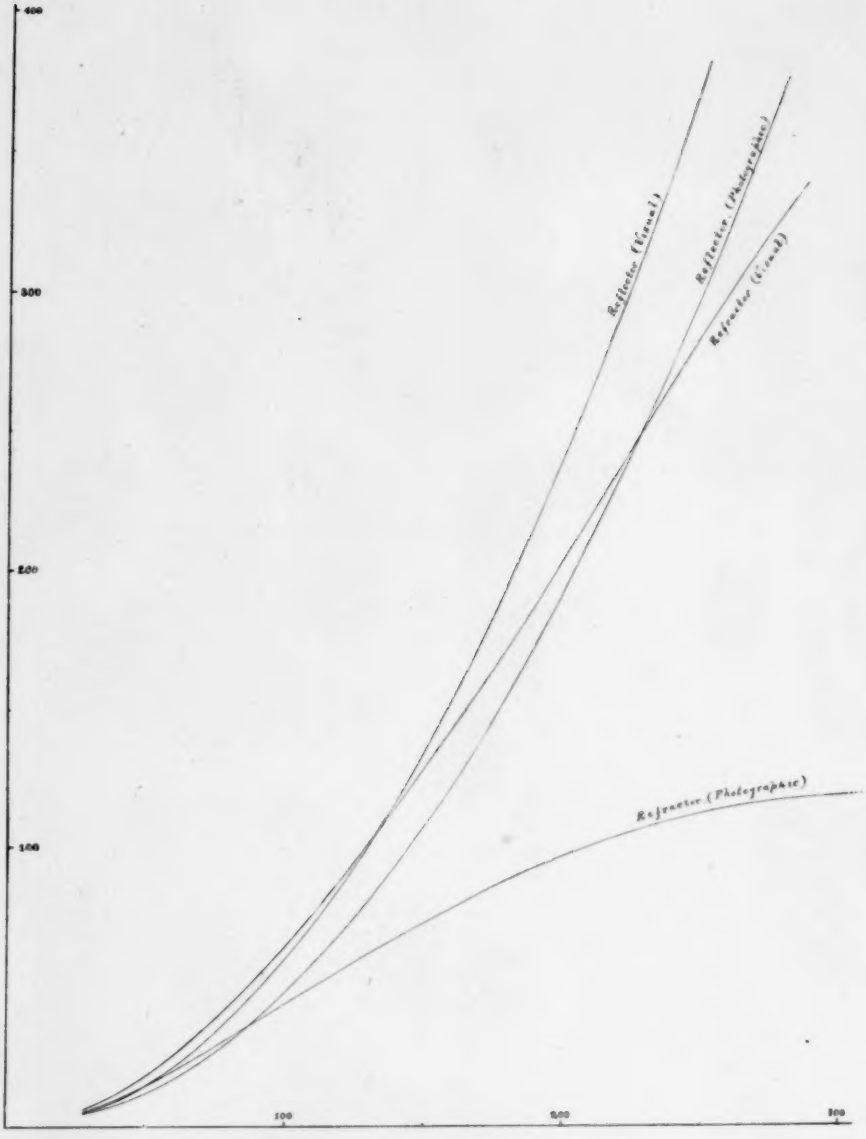
Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3511.763	Mn	0	3518.790	Ni	4
3511.883	Fe	1	3518.825	Fe	3
3511.978	Mn	2	3518.933		0000
3512.066		00	3519.014	Ti, Fe	3
3512.228	Fe	1	3519.239	Tl?	0000Nd?
3512.369	Fe	2	3519.531		0000
3512.520		000	3519.645		0000
3512.639		0000	3519.758		0000
3512.785	Co	6	3519.904	Ni	7
3512.869		00	3520.021		0000
3512.950		00	3520.168		2
3513.100	Fe	1	3520.228	Co	3
3513.200	Fe	2	3520.397	Ti	2
3513.422		0000 N	3520.531		0000
3513.623	Co	5	3520.675	Fe	000
3513.744		000	3520.751		0000
3513.868		00	3520.871		0000
3513.965 s	Fe	7	3520.991	Fe, Zr	2
3514.082		4	3521.118		0000
3514.138	Ni	3	3521.205		0
3514.382		0000 N	3521.318		00
3514.608		0	3521.410 s	Fe	8
3514.775	Fe	2	3521.686		3
3515.206	Ni	12	3521.748	Co	4
3515.549		0	3521.888		000
3515.675		00	3521.984	Fe	2
3515.787		0000	3522.184		0000
3515.947		0000 N	3522.284		0000
3516.021		0000 N	3522.412	Fe	4
3516.156		000	3522.589		00
3516.261		0000	3522.677		0000
3516.359	Ni	2	3522.757		0000
3516.441		0000	3522.877		000
3516.554	Fe, Co	2	3522.974		000
3516.701	Fe	2	3523.048	Fe, Co,-	2
3516.854		0000	3523.212	Ni	1
3516.959		0	3523.324		0
3517.093	Pd	00	3523.452	Fe	2
3517.173		0000	3523.584	Co	4
3517.310		0000 N	3523.700		000
3517.446	-,V	3	3523.850	Co	0
3517.523		0000	3523.924		0000
3517.653		000 N	3524.130		000
3517.860		0000 N	3524.221	Fe	3
3517.960		0000 N	3524.385	Fe	3
3518.103		0000	3524.499		0
3518.200		0000	3524.677	Ni	20
3518.360		0000	3524.883		1
3518.488 s	Co	5	3525.063		000 N
3518.636		0000	3525.271		000 N

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3525.416		0000	3532.143	Mn	4
3525.529		0000	3532.262	Mn	3
3525.656		0000	3532.469		000
3525.759		2	3532.601		0000
3525.986	Fe	4	3532.721	Fe,-	4
3526.103		00	3532.777		00
3526.183	Fe	6	3533.041		0000
3526.311		3	3533.156	Fe	6
3526.398	Fe	2	3533.345	Fe	6
3526.526	Fe	2	3533.506	Co	5
3526.625		2	3533.680		0000
3526.686		0	3533.836	V	000
3526.821	Fe	4	3534.000	Ti	1
3526.988	Co	6	3534.206		0000
3527.115		0	3534.400		000
3527.252		00	3534.672	Fe	2
3527.368		0000	3534.733		0000
3527.458		000	3534.830		0000
3527.588		0000	3534.920	Co	000
3527.672		000	3535.060	Fe	3
3527.750		1	3535.090		00
3527.936	Fe	5	3535.180		0000N
3528.041		0	3535.300		0000 N
3528.133	Ni	4	3535.446	C	000
3528.382		0	3535.554	Ti	4
3528.465		00	3535.660		0000
3528.552		0000	3535.766	C	000
3528.715		0000 N	3535.868		3
3528.928		0000	3535.989		0000
3529.035	Ni	1	3536.165		00
3529.181	Co	3	3536.259		0000
3529.328		00	3536.405		0000 N
3529.495		00	3536.709	Fe	7
3529.662	Fe	2	3536.832		0000
3529.768	Ni	1	3536.934		00
3529.872		00	3537.025		0000
3529.964	Fe-Co	6	3537.105		00 N
3530.136		0000	3537.265		0000Nd?
3530.264		0000	3537.385	Ni, C	1
3530.374		0000	3537.439		0000
3530.533	Fe-	3	3537.638	Fe	2
3530.734	Ni, Ti	1	3537.772	Co	0
3530.919		3	3537.879	Fe	3
3531.107		00	3538.045	Fe	4
3531.247		0000 N	3538.219		0000 N
3531.424		0000 N	3538.399		1
3531.582	Fe	2	3538.452	Fe	1
3531.761		0000	3538.555		0000
3531.851		1	3538.643		1
3531.982	Mn	3	3538.701	Fe	2

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3538.832		0000	3544.888		0000
3538.937	Fe	1	3545.001		0000
3539.081	C	00	3545.054	C	000
3539.218	C	00	3545.128	C	000
3539.391		0000	3545.194		0000
3539.513		0000	3545.336 s	-,V	4
3539.588		000	3545.481		0000 N
3539.684		0000	3545.654	C	0
3539.771		0000	3545.786	Fe, C	5
3539.892		00	3545.971	Fe, C	3
3540.038	C	00 N	3546.048		0000
3540.098		0000	3546.161		0000
3540.268 s	Fe	5	3546.348		1
3540.464	C	000	3546.488		0000
3540.538		000	3546.568		0000
3540.644		0000 N	3546.684		00
3540.857	Fe	3	3546.851	Co	00
3540.950	Fe	2	3546.921		000
3541.108		00 N	3546.974		000
3541.237	Fe	7	3547.121		0000
3541.384		00 N	3547.168	Ti	0
3541.474		000	3547.320		3
3541.687	C	000	3547.362	Fe	3
3541.790		0000	3547.511		0000Nd?
3542.017	C	000	3547.640		0000
3542.129	Ni	0	3547.780		000 N
3542.232	Fe	6	3547.941	Mn	5
3542.397	Fe	3	3548.087		00
3542.473		0000	3548.175	Mn, Fe	3
3542.583		0000	3548.332	Mn, Ni	5
3542.633		0000	3548.447		0000
3542.713	Ti	00	3548.593	Co	00
3542.775	Zr	00	3548.687		000
3542.910		0000 N	3548.793		0000
3543.090		0000	3548.880		0000
3543.143		0000	3549.047		0000 N
3543.243		0000	3549.151 s	Y ?	2
3543.310		0000	3549.260		0000
3543.407	Co	2	3549.384		1
3543.531	Fe	2	3549.513	C	0
3543.637		0000	3549.667	C	00
3543.824	Fe	3	3549.773		0000
3543.937		0000	3549.907		0000Nd?
3544.075	C	0000	3550.014 s	Fe	3
3544.155	C	000	3550.247		0000
3544.229		0000	3550.363	C	1 N
3544.371		1	3550.510		000
3544.489		0000	3550.627	C	0000
3544.662		000	3550.740	Co	4
3544.776	Fe	3	3550.939	C	000 Nd?

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3551.092	C	0000 N	3557.036		3
3551.253		1	3557.204		0000
3551.376	C	000	3557.304		000
3551.542		000	3557.370		000
3551.674	Ni	4	3557.495		00
3551.800		1	3557.604		0000
3551.912		0000	3557.817		0000
3552.012		0000	3557.907		0000
3552.098	Zr	1	3558.020		0000 N
3552.253	Fe	2	3558.140		0000
3552.449		0000 N	3558.214		1
3552.574		0	3558.350		000
3552.699		0000	3558.477		00 N
3552.866	Co	1	3558.570		0 N
3552.986	Fe	5	3558.672 s	Fe	8
3553.086		000	3558.774		0 N
3553.132	Co	1	3558.923	Co	1
3553.236		000	3559.017		0000
3553.304	Pd	00	3559.124		0000
3553.416		0000	3559.219	Fe	1
3553.491		0000	3559.347		00
3553.624	Ni	3	3559.414		0000
3553.735		0000	3559.604		1
3553.887	Fe	5	3559.656	Fe	3
3554.011		000	3559.750		0000
3554.115		0000	3559.840		0000
3554.263	Fe	5	3559.954		000
3554.418		000	3560.063	Ni	0
3554.438		0000	3560.216		00
3554.593		2	3560.303		000
3554.651	Fe	3	3560.436		000 N
3554.789		1	3560.556		000
3554.938		0 N	3560.649		0000
3555.079	Fe	9	3560.729		1
3555.185		0 N	3560.843	Fe	2
3555.318		000 N	3560.942		0000
3555.425		0000	3561.037	Co	4
3555.498		0000	3561.203		0000
3555.598		2	3561.276		0000
3555.758		0000	3561.419		0000
3555.865		0000	3561.516		0000
3555.945		0000	3561.609		0000
3556.088		000 Nd?	3561.718	Ti	1
3556.291		000	3561.796		0000
3556.405		0000	3561.898	Ni	3
3556.515		0000	3562.043	Fe, Ti	1
3556.631		0000	3562.161		0000
3556.738	Zr	2	3562.236	Co	0 N
3556.830	Fe	2	3562.331		0000
3556.944	Fe	4	3562.410		1

PLATE III.



LIGHT GRASPING POWER OF OBJECTIVES AND SPECULA.

ON THE COMPARATIVE VALUE OF REFRACTING AND REFLECTING TELESCOPES FOR ASTROPHYSICAL INVESTIGATIONS.

By GEORGE E. HALE.

EVERY astrophysicist whose investigations include the spectroscopic study of both the Sun and the stars, must have frequent occasion to contrast the instruments available for use in these two fields of research. In the case of the Sun, the brightness of its light permits the employment of finely ruled gratings of very high resolving power, by means of which it is possible to detect a motion of fifty meters per second in the line of sight. For the production of stellar spectra, on the contrary, the most powerful spectrographs used with the largest telescopes contain no more than three large prisms. With the modest resolving power of such an optical train surprisingly concordant measures of stellar motions have been made by the aid of photography, and investigations of this character can be advantageously prosecuted for many years to come. But those who wish to materially reduce the probable error of wave-length determinations of lines in stellar spectra, either for the purpose of increasing the accuracy of line of sight measurements or to render possible such detailed studies of certain lines as are now made in the solar spectrum, must be content to wait for the construction of telescopes much larger than the great instruments of the present day. It thus becomes a matter of importance to the astrophysicist to consider just what advances in telescope construction are most likely to assist him in his work. Naturally the first question that arises is this: Which form of telescope is the better adapted to stellar spectroscopic and other astrophysical investigations—the refractor or the reflector? It is the purpose of the present paper to point out some of the more important advantages for many classes of astrophysical work which the reflecting telescope seems to possess.

For the sake of preventing possible misapprehension, I wish to point out that the observations for which the reflector seems to be best suited should be sharply distinguished from those for which the refractor has been shown by experience to be the better instrument. In direct visual observations requiring perfect definition the refractor seems to give much better results than the reflector. This may be due to a variety of reasons, of which the most potent seems to be the peculiar sensitiveness of a speculum to variations of temperature and flexure. It is not unlikely that the difficulties due to flexure can be done away with by adopting some such form of support for the speculum as that devised by Mr. G. W. Ritchey, optician of the Yerkes Observatory, which is described on another page.[1] The deformation of the mirror resulting from temperature changes cannot be so easily overcome, but its effect upon the image can be lessened by selecting glass as homogeneous as possible for the speculum, so that the distortion may be of a uniform character. But whether the reflector can be ultimately made to compete with the refractor in direct visual observations it is not my object to discuss at the present time. The work for which the reflector seems to be best adapted includes stellar, planetary, and nebular spectroscopy, photometric, and other radiometric studies of the Moon and planets, and photography of stars and nebulæ; it is to the needs of such observations that special consideration is given in this paper.

For such investigations it may said that the perfection of definition required, for example, in double star observations, is to a large extent superfluous.[2] It cannot be doubted that the reflector, even in its present form, defines quite well enough for all work of this character. In stellar spectroscopy, for instance, the unsteadiness of the stellar image on the slit, due to atmospheric disturbances, is ordinarily such as to completely mask any outstanding spherical aberration. Moreover, the sharpness

[1] See p. 143.

[2] See in this connection Professor Wadsworth's remarks in this JOURNAL, May 1896, p. 347.

of the spectral lines depends only upon the width of the slit, when this is not greater than the effective diameter of the "tremor disk." In the other classes of astrophysical work, almost without exception, to which reference is here made, great perfection of definition is equally unnecessary. Thus the most important objection that can be urged against the reflector has little weight in the present connection.

The relative advantages of refractors and reflectors have been so admirably summed up by Sir Howard Grubb in his memoir "On Great Telescopes of the Future,"[1] that I could hardly do better than to repeat his words. As, however, great improvements have been effected in the manufacture of glass for both lenses and specula since 1877, when this discussion was published, and as I wish to give special attention to the astrophysical side of the question, I shall deviate somewhat from Sir Howard's manner of treatment, at the same time acknowledging my obligations to his important paper.

The principal advantages of a reflector, as compared with a refractor, may be outlined as follows:

1. *Perfect freedom from chromatic aberration.*—That this is a matter of the first importance in astrophysical work can be best appreciated by those who have done spectroscopic work with large refractors. In the Lick telescope the focus for the line *Hδ* is $81^{mm}.5$ beyond that for D_2. In the Yerkes telescope the corresponding difference is even greater, so that it has been necessary to give the collimator of the stellar spectrograph a range of motion of 150^{mm}. This dependence of focus upon wavelength seriously hampers all classes of spectroscopic work. In investigating the spectrum of a star, the Sun's chromosphere, or any other celestial object, the slit of the spectrograph must be accurately set in the focal plane of the line whose position or intensity is to be determined. Should this line happen to lie on a steep part of the color curve, the rapidly broadening spectrum on either side of it will fail to show faint lines, and incorrectly represent the intensities of brighter ones. For the purpose of

[1] *Trans. R. Soc. Dublin*, New Series, Vol. I, Memoir No. 1.

making comparisons of the relative intensities of various lines in the same spectrum, it is therefore evident that a large refractor can be used, if at all, only with great difficulty. In observing the forms of the solar chromosphere and prominences in various lines it is essential to success that the slit be placed with great exactness in the focal plane of the line in use. It is a very troublesome matter with large spectroscopes to effect this adjustment whenever it is desired to pass rapidly from one line to another. Moreover, in the case of a refractor, the magnification also depends upon the wave-length, so that photographs of prominences or of the Sun's surface taken in different lines with the spectroheliograph cannot be accurately compared without reduction to the same scale. For work with the bolometer, radiomicrometer or thermopile the single focal plane of the reflector is almost indispensable. In determinations of the colors of stars, planets, Sun-spots and similar objects made with a refractor, uncertainty often enters, because of the chromatic aberration. In photometric observations of objects having different spectra, unless the spectra themselves are compared wave-length for wave-length, the reflector will yield more trustworthy results than the refractor. A further matter of great importance is the fact that the whole field of celestial photography lies open to a reflector, which can also be used, without change of any kind, for visual observations. With the ordinary form of refractor either a separate objective must be used for each class of work, or the visual object-glass must be provided with a third correcting lens, or made with the front lens reversible to adapt it for photography. In a word, it would be hard to name a branch of astrophysical work in which the chromatic aberration of the refractor is not a serious drawback.

The interesting and valuable experiments instituted at Jena by the firm of Schott & Co. have resulted in the production of varieties of flint and crown glass with which objectives having little or no chromatic aberration have been successfully made. Unfortunately, however, the glass was found to deteriorate in a short time, a thin opaque film forming on the surface. Recently

Messrs. T. Cooke & Sons have brought out an objective composed of three lenses, which is said to be practically free from chromatic aberration, so far as the visible spectrum is concerned. I do not know that any objectives of large aperture have as yet been constructed on this plan, which of course involves increased cost of manufacture and the added loss of light by absorption and reflection in the third lens. A correcting lens placed over a visual objective to adapt it for photographic purposes is objectionable on account of the change of focus produced, the loss due to additional absorption and reflection, the inconvenience of attaching and detaching a heavy lens and cell and rebalancing the telescope, and the cost. For spectroscopic purposes a small lens placed near the focus would probably be much more satisfactory, as in this case most of the objections urged against a large lens attached to the objective are less serious. However, the field of the corrected objective would be very small, and the telescope would still not be adapted for work in the ultra-violet and infra-red. The new objective of Professor Hastings, which includes a third lens not far from the focus, shows little or no trace of secondary spectrum to the eye. But no combination of lenses yet devised can compare with a paraboloidal mirror in the capacity to unite in a single focal plane all wave-lengths from the extreme infra-red to the ultimate limit of the ultra-violet. Whatever may be the defects of the reflecting telescope, this property, so important in the estimation of the astrophysicist, must certainly be credited to it.

2. *Relatively small absorption for large apertures.*— In an object-glass composed of two lenses light is lost by reflection at four surfaces. The nature and amount of the absorption depend upon the quality of the glass used, but in all cases the most marked effect is in the ultra-violet. As a consequence it is impossible, even with a photographic objective corrected especially for this region, to photograph any considerable part of the ultra-violet spectrum of a star. The reflector, on the contrary, as Dr. Huggins' results so well attest,[1] serves admirably in photo-

[1] His spectrum of Vega reaches λ 2970.

graphing the shortest wave-lengths that penetrate our atmosphere. At the other end of the spectrum glass becomes less and less transparent for the longer waves, and beyond 2^{μ} is practically opaque. Here a reflector exercises almost no absorption and is consequently indispensable for all thermal investigations in the extreme infra-red.

With the aid of the important photometric determinations of the absorption of various kinds of optical glass recently made at Potsdam,[1] we may compare the light-grasping power of specula with that of the best modern objectives. Thanks to the firm of Schott & Co., of Jena, it was possible to select the flint and crown glass for the great Potsdam refractor from a number of samples having different coefficients of absorption. The absorption was determined for various wave-lengths between λ 6770 and λ 3900, and the samples giving the smallest absorption were chosen for the new objective of 80^{cm} aperture. With the data obtained for these chosen specimens of crown and flint glass a table was prepared, giving the absorption for various thicknesses from 4^{cm} to 40^{cm}. To extend this table so that it shall include the absorptive properties of reflecting telescopes, it remains for us to determine the light-grasping power of silvered specula.

In his memoir on "Energy and Vision"[2] Professor Langley gives the following table of the coefficients of reflection from two surfaces of silver. The wave-lengths are expressed in microns.

Wave-lengths - - -	.35	.38	.40	.45	.50	.55	.60	.65	.70	.75
Reflection, two surfaces -	.37	.54	.63	.73	.79	.82	.845	.86	.875	.885

The table is stated to be "for the selective absorption of silver referred to such a lamina as is spread by the Martin process

[1] H. C. VOGEL: "Die Lichtabsorption als maassgebender Factor bei der Wahl der Dimension des Objectivs für den grossen Refractor des Potsdamer Observatoriums." *Sitzber d. K. Akad. d. W. Berlin*, 19 November, 1896, pp. 1219–1231. For a translation of this article see p. 75.

[2] *Mem. Nat. Acad. Sci.*, **5**, 10.

on the front surface of the glass in its ordinary application. It is prepared from unpublished observations made by the writer with the bolometer." Unfortunately there seems to be no statement regarding the freshness of the silvered surfaces, and we are left in doubt as to the length of time they had been in use before the determinations were made. In his article on the "Telescope" in the *Encyclopædia Britannica* Dr. Gill remarks that too great reliance must not be placed on measurements of the reflective power of small, freshly prepared silvered surfaces, and adds that he "has found from experience and careful comparison that a silvered mirror of twelve inches aperture mounted as a Newtonian telescope (with a silvered plane for the small mirror), when the surfaces are in fair average condition, is equal in light-grasp to a first-rate refractor of ten inches aperture, or area for area as 2:3." From Professor Vogel's table (given below) we find that over 77 per cent. of the visual rays would be transmitted by a 10-inch objective of Jena glass. Disregarding the unknown difference in the absorptive coefficients of Professor Vogel's and Dr. Gill's objectives, this would indicate that after the loss suffered in two reflections and that due to the interposition of the small mirror in the path of the rays, Dr. Gill's Newtonian reflector brought to the focal plane about 53 per cent. of the visual[1] rays received by the large mirror. For the photographic rays referred to by Vogel (λ 3900 to λ 4550), Langley's results show that this coefficient would be reduced to about 48 per cent., on the assumption that the ratio of the coefficients of reflection for different wave-lengths is the same for bright as for slightly tarnished silvered surfaces. It is evident that on account of a lack of necessary data some degree of uncertainty must attend these figures. It cannot be said just how much light was cut off by the small plane mirror in Dr. Gill's reflector, as its size is not mentioned. It is safe to assume, however, that its shorter diameter was rather less than one-fifth that of the large mirror, and this ratio may be taken as a constant for all apertures. The loss of light due to the small mirror and its

[1] Taken by Vogel as lying between λ 6770 and λ 4550.

support may therefore be considered about 4 per cent. of the whole.

Since Dr. Gill's paper was written the process of silvering glass surfaces has been greatly improved by Brashear and others. In view of this fact, and also in consideration of the marked difference between his result and those of Langley (the latter having been obtained by methods which may probably be regarded as much more precise than the estimate made by Gill), we shall hardly be likely to overestimate the capacity of the instrument if we consider that 60 per cent. of the visual and 48 per cent. of the photographic rays are brought to the focal plane of a Newtonian reflector. If, as is sometimes the case, an optician is employed to keep the silvered surfaces in a highly polished condition, these coefficients may be increased to maximum values of about 78 per cent. for the visual and 61 per cent. for the photographic rays. The smaller coefficients will, however, be adopted for the purposes of the present comparison.

The following table contains the results on the transmission of light through objectives given by Professor Vogel in the paper already mentioned, together with certain additional data concerning Newtonian reflectors. It is probable that the corresponding values for Cassegrainian reflectors would differ from these in no very great degree, though Sir Howard Grubb remarks that less light is lost in this latter form of instrument.[1] In the first column is given the aperture in centimeters, which is taken as seven times the thickness of the objective, in accordance with Professor Vogel's suggestion.[2] The next five columns are reproduced without change from Professor Vogel's table. The ninth and tenth columns give the percentages of light received at the focal plane of a reflecting telescope after the loss experienced in two reflections, and that caused by the small mirror and its supports. The numbers in the seventh, eighth, eleventh, and twelfth columns are proportional to the amount of light concentrated in a stellar image by refractors and reflec-

[1] *Trans. R. Soc. Dublin*, New Series, Vol. I, Memoir No. 1, p. 2.

[2] See p. 89.

Aperture in cm	Objective						Silvered glass speculum			
	Thickness in cm	Intensity of transmitted light when incident light is unity				Light-grasping power		Intensity of reflected light when incident light is unity (Newtonian telescope)		Light-grasping power	
		With respect to absorption alone		With respect to absorption and reflection							
		Visual rays	Rays most active chemically	Visual rays	Rays most active chemically	Visual rays	Rays most active chemically	Visual rays	Rays most active chemically	Visual rays	Rays most active chemically
28	4	0.93	0.84	0.77	0.69	6.04	5.41	0.60	0.48	4.70	3.76
42	6	0.90	0.77	0.75	0.63	13.23	11.11	0.60	0.48	10.58	8.46
56	8	0.87	0.71	0.72	0.58	22.58	18.19	0.60	0.48	18.82	15.05
70	10	0.84	0.65	0.70	0.53	34.30	25.97	0.60	0.48	29.40	23.52
84	12	0.82	0.60	0.67	0.49	47.27	34.57	0.60	0.48	42.34	33.89
98	14	0.79	0.55	0.65	0.45	62.43	43.22	0.60	0.48	57.62	46.10
112	16	0.76	0.50	0 63	0.41	79.03	51.43	0.60	0.48	75.26	60.21
126	18	0.74	0.46	0.61	0.38	96.84	60.33	0 60	0.48	95.26	76.20
140	20	0.71	0.43	0.59	0.35	115.64	68.60	0.60	0.48	117.60	94.08
154	22	0.69	0.39	0.57	0.32	135.18	75.89	0.60	0.48	142.30	113.84
168	24	0.67	0.36	0.55	0.29	155.23	81.85	0.60	0.48	169.35	135.48
182	26	0.65	0.33	0.53	0.27	175.56	89.43	0.60	0.48	198.75	159.00
196	28	0.62	0.30	0.52	0.25	199.76	96.04	0.60	0.48	230.50	184.40
210	30	0.60	0.28	0.50	0.23	220.50	101.43	0.60	0.48	264.60	211.68
224	32	0.58	0.25	0.48	0.21	240.84	105.37	0.60	0.48	301.05	240.84
238	34	0.56	0.23	0.47	0.19	266.23	107.62	0.60	0.48	339.86	271.89
252	36	0.55	0.21	0.45	0.18	285.77	114.31	0.60	0.48	381.02	304.82
266	38	0.53	0.20	0.44	0.16	311.32	113.21	0.60	0.48	424.53	339.63
280	40	0.51	0.18	0.42	0.15	329.29	117.60	0.60	0.48	470 40	376.32

tors, calculated for both the visual and the photographic rays, allowance having been made for all losses in both types of telescope. They are obtained by multiplying the square of the aperture by the percentages given in the preceding columns.

In Plate III are reproduced curves platted from the light-grasping powers given in the table. Ordinates represent light-grasping power, and abscissæ are apertures. It is evident from inspection of the curves that for apertures not exceeding 87^{cm} refractors surpass (Newtonian) reflectors in light-grasp for both visual and photographic rays. As soon as this aperture has been passed the reflector becomes the more efficient collector of the blue and violet rays, while it still gives images that are less brilliant visually. For apertures over 134^{cm} the reflector gives brighter images than the refractor in both the visual and photographic regions. It will be noticed that this aperture is much greater than the corresponding value (about 90^{cm}) deduced some years ago by Robinson in a comparison of the light-grasping power of objectives and speculum metal mirrors. I have adopted small values of the coefficients of reflection, in order to avoid the danger of exaggerating the light-grasping power of specula. The rapid relative gain of the reflector beyond this point can be best appreciated by a glance at the curve.

It is evident that if the silvered surface be kept in excellent condition the superiority of the reflector will be much greater.[1] If the comparison were extended to the infra-red or ultra-violet the refractor would be shown to be of relatively small importance for work with these rays. The percentage of light reflected by a silvered mirror increases with the wave-length. At 1^{μ} it is 96.5 (one reflection), at 2^{μ}, 97.3, and at 4^{μ} practically all the incident light is reflected. For wave-lengths of 6^{μ} and 8^{μ} the percentage of reflection has been found to be as great for old

[1] It is by no means impossible that large specula may ultimately be coated with a highly reflective film of platinum, as small surfaces are now so successfully treated in the laboratory. The experiments of M. Izarn in covering a silvered surface with an extremely thin film of bichromatized gelatine, to protect it from the air, also seem promising. (*C. R.* **118**, 1314.)

and yellow silvered surfaces as for new ones with perfect polish.[1]

3. *Possible large angular aperture.*— In the case of an objective composed of two lenses it is not common to see a ratio of aperture to focal length greater than $\frac{1}{14}$, and it is practically impossible to make a good objective of this sort with a ratio greater than $\frac{1}{8}$. Specula, on the contrary, may be made with a ratio as great as $\frac{1}{4}$. Of course such specula define well only in the center of the field, but this is quite sufficient for the requirements of stellar spectroscopy and other similar work. Large angular aperture is frequently of great value in stellar and nebular photography, in stellar spectroscopic work, and in bolometric or other thermal investigations of the Moon. Mechanically a short tube is advantageous on account of its rigidity and convenience.

4. *Small cost of speculum, mounting and dome.*— A perfectly figured silvered glass speculum of thirty-six inches aperture costs rather less than $2000. The objective of the Lick telescope, of the same aperture, cost $50,000, or twenty-five times as much. For larger apertures the comparison would be even more favorable to the reflector. On account of their relatively short focal length specula can ordinarily be mounted more cheaply than objectives of the same aperture. For the same reason some saving can be effected in the cost of the dome, which, when the telescope tube is mounted with the declination axis at its center, varies nearly as the square of the focal length of the telescope used under it. In the mounting of reflectors the declination axis is usually placed nearer the mirror, so that the dome must be larger than would be the case if it were central.

5. *Possible large linear aperture.*— The largest objective hitherto constructed has an aperture of one meter. Rough disks of optical glass have, I understand, been made for telescopes of larger aperture to be mounted in Berlin and Paris. In the present state of optical glass manufacture it is perhaps possible to make an objective of 150^{cm} aperture, but both the

[1] E. F. NICHOLS, *Phys. Rev.*, 4, 303, 1897.

glassmaker and the optician would regard such an undertaking as a most formidable one, requiring at least five or six years of labor for its completion. On the other hand a speculum of 180^{cm} aperture has already been made and used by the Earl of Rosse, and the St. Gobain Plate Glass Company offered in 1896 to furnish a glass disk suitable for a speculum of 220^{cm} aperture. It is not improbable that an order for a glass speculum three meters in diameter would be accepted by the glassmaker and the optician, who might be expected to complete the work within a period of two or three years. As Sir Howard Grubb has pointed out in the memoir referred to above, large disks of speculum metal would probably be easier to obtain than glass disks of the same diameter. But the latter are generally to be preferred, on account of their comparative lightness and the ease with which they may be re-silvered without the slightest danger of affecting their figure.

The above considerations seem to show that the astrophysicist may properly consider the reflector to be an even more important part of his instrumental equipment than the refractor. For many of his investigations it is indispensable, and in most cases it offers advantages which more than offset certain other advantages enjoyed by the refractor. For direct visual observations such an instrument as the forty-inch Yerkes telescope, with its superb definition, is probably far superior to any reflector in use. It follows that an observatory which is well equipped for astrophysical research should possess both refractors and reflectors, in order that all classes of work can be prosecuted in the most advantageous manner possible.

As regards the future development of telescopes in the direction of increased light-grasping power, the reflector promises far greater gains than the refractor, especially for spectroscopic work in the so-called photographic region. Indeed, it appears from an inspection of the curves in Plate III, that an increase in the aperture of an objective beyond about 350^{cm} would be attended by no gain in the intensity of the photographic image. In the case of reflectors, on the contrary, the

light-grasping power will continue indefinitely to gain with the aperture.

The great advantages for astrophysical research offered by the *equatorial coudé* reflector, invented in its original form by my late friend Arthur Cowper Ranyard, and described by Professor Wadsworth on another page, point to this instrument as one likely to prove of great service in the future. I am glad to say that Mr. Ritchey will shortly undertake, in the optical laboratory of the Yerkes Observatory, the construction of a speculum of 150^{cm} aperture, which will be provided with a mounting of this type, and devoted exclusively to investigations in astrophysics.

YERKES OBSERVATORY,
January 1897.

ON A NEW FORM OF MOUNTING FOR REFLECTING TELESCOPES DEVISED BY THE LATE ARTHUR COWPER RANYARD.

By F. L. O. WADSWORTH.

INTRODUCTION.

IN a preceding article Professor Hale has reviewed the many advantages which reflectors possess over refractors, particularly for astrophysical work. Personally, I do not think that the former can ever quite equal the performance of the latter for general visual observations, on account of the almost insurmountable difficulties in preserving the figure of the mirror under changes of temperature and changes in position; although, as I have said in a previous paper,[1] the difficulty due to the latter may be to a great extent overcome by making the specula much thicker in proportion to their diameter than has been customary heretofore, and by adopting the counterpoised support system more fully described in Mr. Ritchey's article in the present number. For measurements of position simply the reflector obviously cannot compete with the refractor, nor is there any reason why it should, since the instruments used for such measurements are never of more than what is now regarded as a very moderate size. For celestial photography the reflector is superior in the entire absence of chromatic aberration and greater light-grasping power, and some magnificent photographs, among which those of Common, Roberts, and Wilson stand preëminent, have been obtained by its use. But it is unfortunately impossible to employ it when a large field is desired; for such purposes only a photographic doublet can be used.

Since astrophysical work then offers the greatest field of usefulness for reflectors it is for such work that their mountings

[1] A Review of Professor Johnstone Stoney's article on the "Astrophysical Observatory of the Future." *Ap. J.* 4, 238.

should be primarily designed. There is no doubt that the conditions fulfilled by the cœlostat, or by the Foucault siderostat, are those most favorable for most astrophysical work, and it is on this ground that such instruments have been considered by many as more suitable than the equatorial for the use of the astrophysicist. But, as pointed out in the review already referred to, the equatorial has great advantages on the score of simplicity, ease of control, and minimum loss of light, the latter a very important consideration in the case of stellar spectroscopy. If, then, its mounting can be so designed that the observing instruments are as favorably situated as they are with a siderostat, the only possible objections to its use for all classes of work will have been removed.

The various types of reflector mountings may be divided, so far as the position of the observer or observing instrument with reference to the telescope and its mounting is concerned, into three general classes: the Newtonian, the Cassegrainian, and that class of which the recently invented *coudé* may be taken as a type, in which at least the eye end of the telescope lies in the polar axis. Of the first two forms the second is the most advantageous, because the observing instrument can be attached directly to the stiffest part of the telescope tube, *i. e.*, the support for the large mirror; but it has the disadvantage of requiring a hole through the center of the latter. The last form is the only one which realizes the conditions satisfied in the case of the siderostat; *i. e.*, of a fixed observing instrument situated in an observing room separate and distinct from the dome or space in which the telescope itself is mounted. In the case of the siderostat the axis of the observing instrument is horizontal, while in the case of the *equatorial coudé* it is inclined at an angle equal to the latitude of the place. This, however, is no great disadvantage, as in most cases it is nearly as easy to use the apparatus likely to be employed in astrophysical work in an inclined as in a horizontal position. When the rotation of the image, with respect to the observing instrument, is not detrimental, the latter may be fixed in position on a pier in the

observing room; in other cases it may be attached to a large plate mounted on the end of the polar axis, as shown in the following figures. The great size and stiffness which can be given to this plate enables an instrument of almost any desired size and shape to be rigidly supported on the telescope. The only motion of the instrument when so mounted is one of rotation about its own axis.

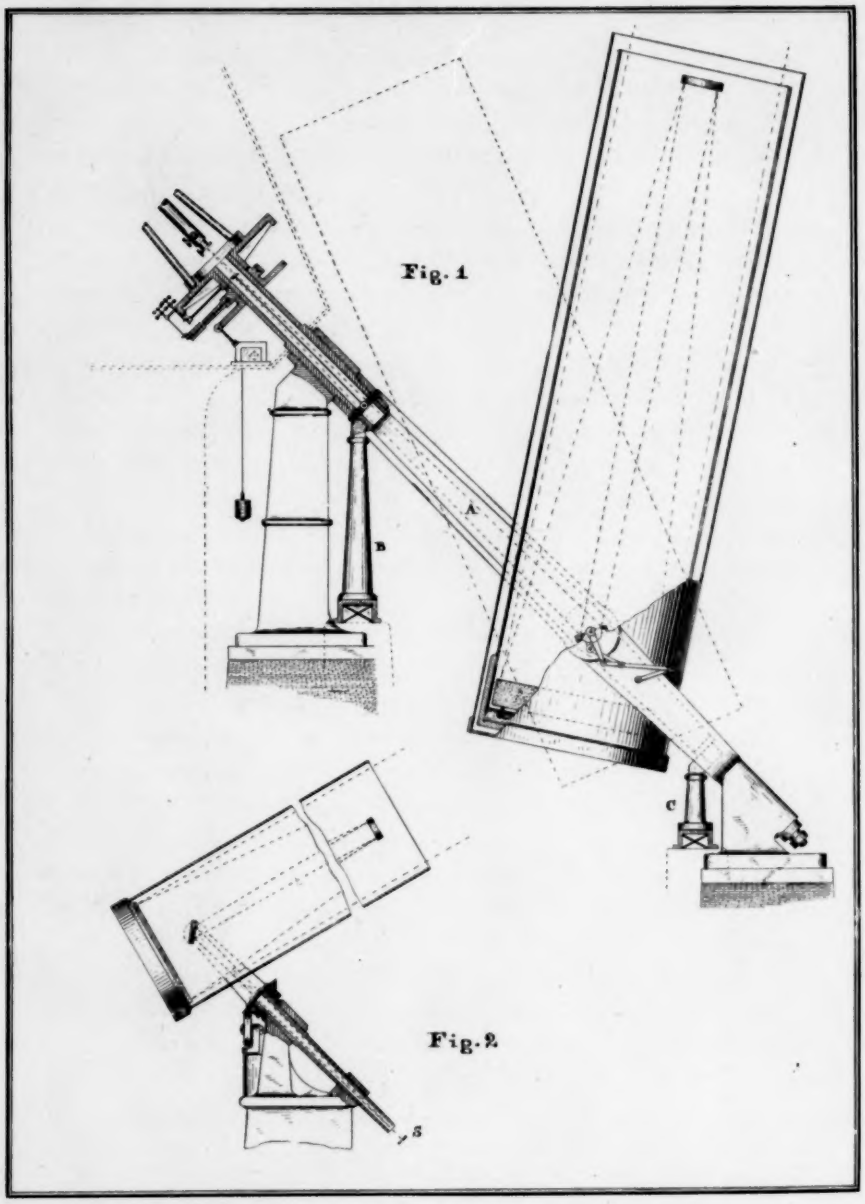
The greatest advantage of such an arrangement is the possibility of keeping the observing instrument at a constant temperature and under constant hygrometric conditions; conditions of great importance in bolometric and solar spectroscopic work, and which can never be realized in an open dome. When one reflects how much the character of an observer's work is likely to be influenced by the conditions under which he works, the minor advantages of personal comfort, and convenience of manipulation, advantages which can only be fully appreciated by those who have had an opportunity of seeing and using one of the *coudé* equatorials, are seen to be also of considerable importance.

Of the various instruments of this general type the two best known forms are the siderostatic telescope of Grubb,[1] which is simply a polar heliostat with a refracting telescope mounted in a prolongation of its polar axis and rotating with it, and the *equatorial coudé* of Loewy already alluded to.

The first has the disadvantage of having a limited range of motion in declination, the second is free from this but requires two large optical flats, each about one and one-half times the aperture of the telescope itself, one of which is in the reflector type of mounting pierced at the center by a hole of considerable size. It was probably with an idea of avoiding the expense of such a construction, while retaining all the advantages of the *coudé* mounting, that Mr. Ranyard first took up the consideration of the subject. It is the principal purpose of the present

[1] Described in the *Proc. Roy. Soc. Dublin*, **2**, 362, April 1880. In a later paper (*Trans. Roy. Soc. Dublin*, **3**, 61, April 1884), Grubb describes another form of mounting which may be called a dialyte *coudé*. No instrument of this form has, so far as I am aware, been built.

PLATE IV.



COUDÉ MOUNTINGS FOR REFLECTING TELESCOPES.

paper to decribe the beautiful form of mounting which he devised to satisfy these two conditions, and which he was prevented by his untimely death from perfecting in its minor details.

DESCRIPTION OF THE FIGURES.

Figure 1 represents in side elevation, partly in section, the original form of Ranyard's mounting, designed on as nearly as possible the original plan conceived by him and communicated to Professor Hale. The details of this mounting were never fully worked out, and had therefore to be supplied in part by the designer. Had Mr. Ranyard himself worked out the plan in full, there would probably have been less ground for criticism of many of these minor features. The polar axis of the mounting is, as will be seen, of the English form, the tube of the telescope being carried in a large closed fork, with bearings at both ends. One of the features of Ranyard's plan was to dispense with the usual dome, and replace it by a second tube parallel with and encircling the telescope tube, and moving with it, although not directly connected to it. As worked out in the present plan, this tube is carried on a fork *A* inside the main telescope fork, the declination axis being concentric with and exterior to the declination axis of the telescope itself. This fork is carried at its upper and lower ends on two pillars, *B*, *C*, which are supported on cross beams whose ends rest on two piers placed outside the two large telescope piers. These pillars, of course, prevent the complete rotation of the fork, but being narrow, allow it to swing through nearly 170°, and therefore work to within 5° of the horizon on each side.

The main feature of the Ranyard mounting is a mirror mounted in the declination axis and connected with it in such a way that it moves at half the angular speed of the latter.[1] The arrangement shown in the figure for accomplishing this is one which was designed by the writer to take the place of the usual

[1] This is also the essential feature of the dialyte *coudé* of Sir Howard Grubb, already referred to (see preceding footnote).

"minimum deviation" motion used in prism spectroscopes. It was fully described in a paper in the *Phil. Mag.* for October 1894[1]. The light from the speculum is normally reflected from a small convex mirror at the upper end of the tube, as in the ordinary Cassegrainian form, but instead of passing back through the center of the mirror, it falls upon this reflector just mentioned and by it is reflected up through the polar axis, which, as shown in the figure, is hollow. The upper end projects through the wall of the observing room, as in the *coudé* form of mounting, and to it are attached the driving-worm, the right ascension circles, and the arrangements for clamping and moving the telescope in right ascension and declination. The rods for this latter motion are carried down on one side of the opening in the axis, so as not to interfere with the cone of light.

Although the general idea of this mounting is, in my opinion, admirable, it has some few defects both of an optical and a mechanical nature, the latter of which might, as I have already said, have been avoided by Mr. Ranyard if he had carried out the design himself. Two of the greatest objections are: first, the inability to cover the entire heavens (the instrument as here designed being able to approach only to within about 25° of the pole); and second, the fact that for positions near this the line of sight is directly over the roof of the observing room and definition is likely to be seriously interfered with by the current of warm air from the latter. This last objection could be more or less done away with by making the roof of the building double and arranging for a circulation of air between the outer and the inner wall. But it will be seen that the room for this is very limited on account of the spectroscope projecting upward toward the ceiling of the room at an angle of about 45° in the present case. For lower latitudes this difficulty would of course be less.

To avoid these difficulties I have designed three modifications of the mounting, which are here presented, not because they offer a complete or fully satisfactory solution of the prob-

[1] "Fixed Arm Spectroscopes," *Phil. Mag.*, **38**, 337; *A. and A.*, **13**, December 1894.

lem, but in the hope that they may suggest to someone else a still better form.

In the first of these, shown in Fig. 2, the large speculum is mounted in a short, heavy fork at the upper end of the polar axis (as in the recent three-foot reflectors of Dr. Common and Lord Rosse). The small speculum and the movable reflector are mounted in the same manner as before, except that the latter is arranged to throw the light down the polar axis instead of up, and the driving-wheel, right ascension circle, clamps, spectroscope ring and observing instrument are all placed at the lower end of the axis instead of at the upper end, as in the preceding form. The whole polar axis is supported at its center of gravity on a single wheel, *A*, mounted on ball bearings, an arrangement which was suggested and described by the writer in the October number of *A. and A.* for 1894.[1]

It will be seen at once how much more advantageous this arrangement is as regards the position of the observing room with reference to the telescope itself. With this form it is only possible to sweep from the southern horizon to within about the same distance from the pole as in the preceding form, but the telescope may be revolved through 360° without interfering with any part of the mounting. It can be arranged to go even closer to the pole by making the fork longer, but this would not be worth while, as when it is necessary to examine objects close to the pole the reflector at the lower end of the tube can be raised slightly above its usual position and turned at right angles so as to throw the light along the top of the declination axis. The spectroscope or other observing instrument can then be mounted directly on the latter, as shown in Fig. 5.

With this form a greater length of flat is necessary for objects at or near the zenith, but not so great a length for objects near the horizon as in Ranyard's form. Since the major-

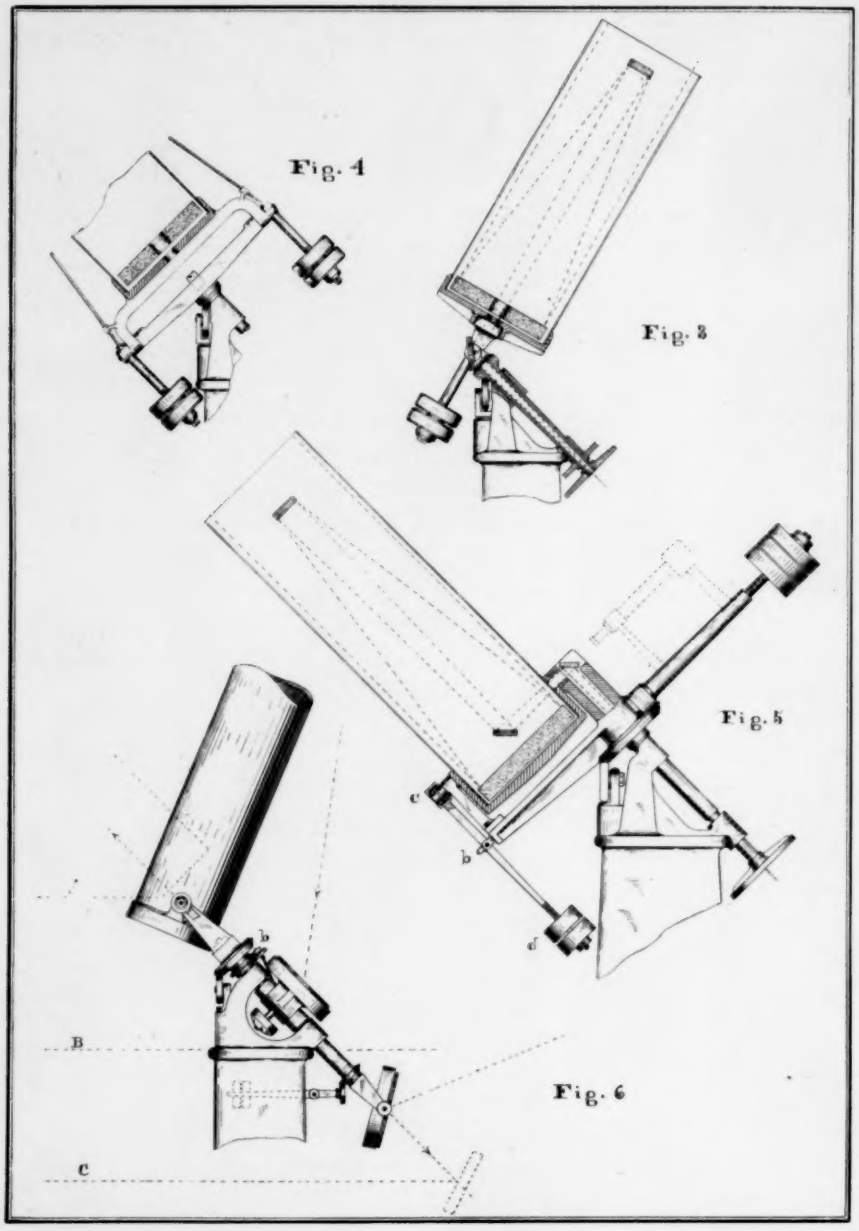
[1] I have since learned that this same device was previously used by the Repsolds in the mounting of the Pulkowa refractor. It is highly commended by Dr. Gill in the *Enc. Brit.* (see 9th ed. **22**).

ity of work is done by preference on objects near the zenith, the latter has the advantage in this respect. But aside from the increased length of the reflecting surface rendered necessary, the high angle of incidence is an advantage in diminishing the effect of errors of the flat and in diminishing the loss of light by this reflection. Moreover, the distance from the flat to the focus can, as will readily be seen, be made much less than when the light is sent up the axis, and a shorter equivalent length of focus therefore obtained.

To avoid the necessity for changing the arrangement of the instrument for objects near the pole another modification of the mounting shown in Fig. 3 was devised. The arrangement is very similar to the Cassegrainian mounting except for the introduction of the reflector in the declination axis as already described. The light from the convex mirror passes through the center of the large speculum and falls on the flat, which is in this case placed behind the speculum. The form of the mounting necessary to carry out this idea is somewhat similar to the old saddle-back mounting, but is much neater in general appearance, as the counterpoise weights and telescope tube are in one straight line. The fork on which the declination axis is supported is attached to the lower end of the telescope tube instead of to the upper end of the polar axis as in the preceding form, and can, as will be readily seen from Figs. 3 and 4 (the latter representing the instrument pointing directly at the pole), be made much shorter than before, while still allowing the instrument to sweep over the entire heavens. Another advantage of this reversed arrangement is that the center of gravity of the telescope, which when the instrument is in balance lies at the intersection of the declination and polar axes, is thus brought nearer the upper end of the latter.

In all the instruments so far described the flat has had to be unusually long for certain positions of the instrument, and in the case of the first two forms it has only been possible to cover a portion of the sky without rearrangement of some part of the instrument. The form next to be described avoids all of these

PLATE V.



COUDÉ MOUNTINGS FOR REFLECTING TELESCOPES.

difficulties, but only at the expense of an additional reflection. It has however the advantage of requiring no relative motion between the flat in the declination axis and the telescope tube. In measurements of position this might become of considerable importance, although if the link motion already described is used for connecting the flat with the declination axis, there is much less chance of error than in the ordinary minimum deviation motions. In this form, which is shown in Fig. 5, one reflector is arranged as before in the declination axis, but is turned at 90° to its former position so as to reflect the rays along this axis instead of along the polar axis. The second reflector is then placed at the intersection of the polar and declination axes, in such a position as to reflect the light down the latter. These two small reflectors are rigidly fixed in position with respect to the declination and polar axes respectively, and as will readily be seen, bear the same relation to each other as do the two large reflectors in the *coudé* equatorials. If desired for any particular purpose the second reflector may be removed and the spectroscope or other observing instrument mounted directly in the declination axis, as shown by the dotted lines in the figure. The arrangement for relieving the friction on the polar axis is the same as in the preceding two forms, but on account of the overhanging of the fork which carries the outer end of the declination axis in this form, a special device has been introduced for transferring about 90 per cent. of pressure from this point to another point much nearer the end of the polar axis. This is accomplished by means of a lever, which is pivoted on a ball and socket or gimbal joint at *b* and has at its upper end a ring of U shaped inner section, *c*, which surrounds the declination axis. Between each arm of the U and a steel flanged collar on the declination axis is a row of balls. On the other end of the lever is placed a weight *d* of such mass that its moment about *a* is equal to the moment of about 45 per cent. of the mass of the telescope, acting at *c*.

The remaining 5 per cent. of the pressure on the outer fork arm is easily supported by the latter even when it is compara-

tively light without danger of flexure.[1] The inner support of the declination axis is a prolongation of the polar axis itself, and is in consequence so stiff and rigid that there is no necessity of relieving the pressure upon it so far as any danger of flexure is concerned. By placing the arm which carries the counterpoise in right ascension in line with the base of the fork, the center of mass of the telescope, fork, and counterpoise weights is brought so near the end of the polar axis, that only a slight weight on the end of that axis is sufficient to bring the center of gravity of the whole revolving system directly over the friction wheel under the upper end of the polar axis. Ordinarily this weight would be furnished by the spectroscope or observing instrument attached to the lower end, so that no dead weight is really necessary.

It has not been thought necessary to show in these latter three figures the details of the slow motions, circles, etc. Their arrangement is perfectly obvious.

In this connection it may also be interesting to show a form of mounting which has suggested itself as especially adapted for astrophysical observatories, in which three separate and distinct instruments are carried on the same mounting without interfering in any way with each other. This arrangement is shown in Fig. 6. It consists of a large reflector mounted in the same way as in Fig. 5, except that the second reflector is turned through 180° so as to reflect the light up the axis instead of down. As the telescope itself is mounted to one side of the polar axis, a small observing room into which the spectroscope may project, may be built in the prolongation of this axis without interfering with the motion of the telescope, even when the latter is pointed toward the pole. The polar axis of the reflector mounting is hollow, as before, and through it projects a second axis which carries at its lower end the fork of a polar heliostat, which may be supported as shown, by a second independent friction

[1] This same method of removing the pressure from the outer ends of the fork might be used with advantage in the case of the mounting shown in Fig. 2. The fork arms could then be made much lighter than has been possible in previous mountings of this kind.

wheel placed at the center of gravity of the fork and its axis, so as to entirely relieve the friction between the two axes. The two axes may be clamped together so as to revolve as one when desired, and since one may be moved into any position with reference to the other, two entirely separate objects can be followed at the same time. Between the two forks in which the polar axis of the telescope is mounted is a sleeve having its bearing on the moving axis of the reflector, and carrying a cœlostat mirror. This is normally free on the telescope axis, but may be connected with it by gears, *b*, so as to be made to revolve with it at half the angular speed. This cœlostat mirror may then be set on any third object, and when connected as just described to the telescope axis, will of course follow this object. We have, therefore, the first instrument, viz., the reflector, with which observations are carried on on a floor *A;* a second instrument, the polar heliostat (which may if desired be replaced by any form of siderostat), with which observations are carried on at a level *C;* and the third instrument, the cœlostat, with which observations are carried on at the intermediate level *B*, each working entirely independently of the others. In the case of very large instruments the cost of the mounting, as is well known, is more than half the cost of the whole instrument, and the combination of three instruments on one mounting would therefore effect a very considerable saving in the aggregate cost of the whole combination, besides utilizing space in the observing dome to much better advantage than is usually done.

The large cost of the usual form of revolving dome compared with the cost of the instrument for whose protection it is designed raises again the question as to whether some cheaper and at the same time efficient arrangement cannot be invented to take its place. With the original *coudé* forms this dome is not necessary, or rather its place may be taken by a simple form of wind screen to insure stability in high winds.

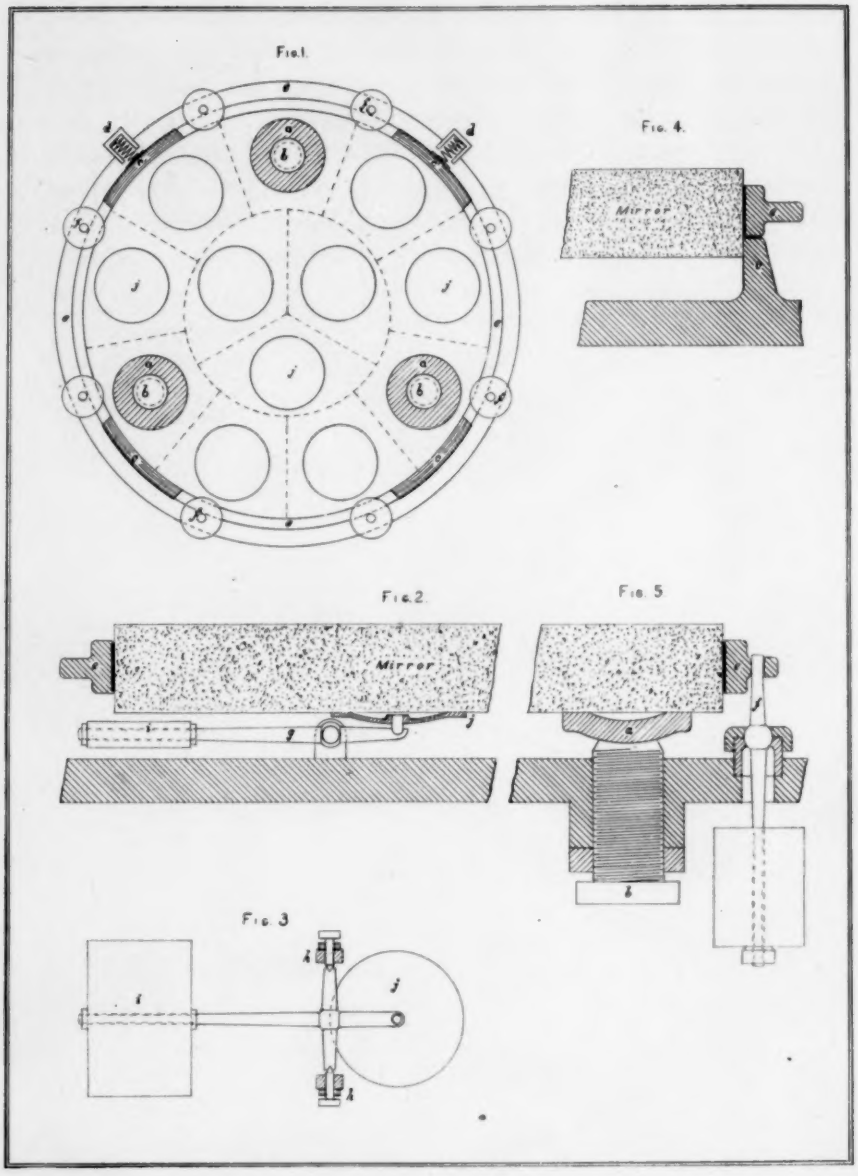
In Ranyard's form, however, something more is necessary, and his plan of using an outer protecting tube instead of a large

dome seems a step in the right direction. There are, however, great mechanical difficulties to be overcome, and the plan of mounting this tube shown in Plate IV, must be regarded as only a crude attempt to illustrate how the idea may be carried out. I have under consideration a number of other plans of protection both for these forms and for the ordinary refractor mountings (the general idea of one of these plans was sketched in a recent number of this journal),[1] but none of them have been developed sufficiently to warrant description at the present time.

YERKES OBSERVATORY,
January 1897.

[1] *Ap. J.* 4, 240.

PLATE VI.



SUPPORT SYSTEM FOR LARGE SPECULA.

A SUPPORT SYSTEM FOR LARGE SPECULA.

By G. W. Ritchey.

In properly supporting a large telescope mirror in its cell, to secure at once freedom from flexure and great stability of position of the mirror, a degree of care and refinement is demanded which is not necessary, to the same extent, at least, in the case of an objective; for, as is well known, flexure of a telescope mirror is directly injurious to the sharpness of the focal image, there being no inherent partial correction or compensation such as occurs in case of flexure of an objective. And there is another somewhat similar consideration: a tilting of the mirror in its cell directly affects the position of the focal image, while with an objective such a change of position is compensated for as in the case of flexure. When the mirror or objective moves in its own plane, the effect on the position of the image is direct, and is, in general, the same in both.

The beautiful mirror-support systems devised by Lassell, Grubb, Common, and others, while probably leaving little to be desired so far as supporting the mirror without flexure is concerned, certainly do not give the very great stability of position which is desirable in view of the considerations named above, and in view, also, of the fact that the most promising lines of work for the reflector are in the direction of photography and spectroscopy, in which long exposures are necessary, with the utmost attainable precision in pointing and following.

The mirror support system described below was devised for the purpose of affording a "flotation" support which would be not inferior to the best hitherto in use, and at the same time of affording a very high degree of stability of position of the mirror in its cell. It was designed by the writer many years ago, but has not hitherto been published, though the detail drawings were shown to Professor Hale in 1891.

The back support.— Let us consider the mirror to be divided into twelve imaginary segments of equal weight (see Fig. 1, Plate VI). The back of the mirror rests, primarily, upon three strong hardened steel plates, represented by the three shaded circles *a* Fig. 1, and at *a* Fig. 5, the center of each plate being directly back of the center of weight of the corresponding segment. The upper surface of each of these plates is ground to fit the back of the mirror; the lower surface is slightly convex and is ground to fit a corresponding concave in the upper end of each of the three large adjusting screws for adjusting the optical axis of the mirror, these adjusting screws projecting slightly through the massive casting which forms the mirror cell. This is shown in Fig. 5. It will be noticed that these three plates are near the edge of the mirror, in the outer ring of segments, and that the base of support is therefore much larger than in the support systems mentioned above. It is evident that by properly designing these steel plates and the adjusting screws which support them, we can fix with great stability the plane of the mirror which rests directly upon them, their being no *building out* from these three primary points of support — no intermediate levers as in the older systems.

Now the weight of the remaining nine segments of the mirror is just balanced by means of nine weighted levers, entirely independent of each other, which lie in a plane parallel to the back of the mirror. One of these levers is shown at *g* Fig. 2, and in plan in Fig. 3. These levers are suspended between pivots screwed through lugs projecting from the cell. The small cone-bearings *h* Fig. 3, are carefully made to reduce friction. The long arms of these levers carry adjustable lead weights (*i*, Figs. 2 and 3) which, in order to occupy as little space as possible perpendicular to the plane of mirror, are in the form of plates instead of cylinders; the short arms of the levers are thus made to press against the back of the corresponding segments through the medium of light plates, represented by the unshaded circles in Fig. 1, and at *j*, Fig. 2.

Let us suppose that the mirror weighs 120 pounds. With

the cell in a horizontal position the lead weight on each lever would be adjusted by means of a standard weight of ten pounds placed upon the plate on the short arm. This adjustment being completed, if the mirror be now laid upon the support system the nine levers will, of course, carry ninety pounds of the weight of the mirror, and the remaining thirty pounds will be distributed equally upon the three plates on the upper ends of the adjusting screws. Thus each of the twelve segments of the mirror, weighing ten pounds apiece, will be balanced, independently, by a pressure of ten pounds exerted directly against it from beneath. Now suppose that the edge support of the mirror, which will be described below, be introduced and the entire system inclined in any direction and at any angle. It is evident that, so far as the back support is concerned, there will still be a perfect balance maintained; and this whether the levers lie in such a direction that the vertical planes through the length of the levers are parallel to the vertical plane through the axis of the telescope tube, or not.

The edge-support.—The connection between the back-support and edge-support is so intimate that any inefficiency in the latter will effect injuriously the operation of the former, however perfect that may be in itself. In an equatorially mounted mirror, different points of the edge of the mirror become successively lowest, of course, as the position of the telescope is changed. In the flexible band and cushioned edge-support so much used in England, the heavy mirror therefore necessarily changes its position, laterally, with respect to its cell, in taking its bearing down against the edge-support; thus not only is stability lost, but this tendency to lateral shift must impair the freedom of operation of the back-support system.

In the plan under consideration four metal arcs are used (*c*, *c*, *c'*, *c'*, Fig. 1) for the purpose of fixing the position of the mirror laterally; two adjacent arcs are cast directly on the cell, as at *c*, Fig. 4; the other two, diametrically opposite these, exert a slight pressure against the edge of the mirror, by means of weak springs, for the purpose of holding it against the stationary

arcs; this pressure need amount to only a very small percentage of the weight of the mirror, for all of the lateral pressure due to the weight of the mirror, when in oblique positions, is carried by a stiff metal ring (*e*, Figs. 1 and 5) which encircles the edge of the mirror, and fits it loosely, a thin band of hard leather being inserted between the ring and glass. This ring is suspended by three short wires from the telescope tube above, so that if the mirror were removed the ring could swing freely in its own plane. This ring is pressed against the edge of the mirror, when the latter is inclined, by a series of eight short weighted levers (*f*, Figs. 1 and 5) which hang perpendicularly to the plane of the ring. These levers are suspended from the cell-plate behind the ring by means of ball-and-socket joints, or preferably, to reduce friction, on pivoted universal joints. The ends of the short upper arms of these levers fit loosely into holes in the ring; the lower ends carry lead weights, the adjustment of which, so that the eight levers will just balance the combined weight of the mirror and edge ring, is effected in a manner very similar to that described in the case of the levers for back support.

Remarks.— It will be noticed that the edge-support and back-support systems work together well. The latter is always free from the great constraint and friction which any tendency to lateral shift of the mirror would introduce.

The number of segments independently balanced by the back-support system may of course be increased in the case of very large or thin mirrors. An incidental advantage which occurs when this is done is that the base of stable support afforded by the three plates on the adjusting screws, will be still larger, compared with the size of the mirror, than when twelve segments are used.

All of the levers used in the back-support can be exactly alike, as can also the eight levers used in the edge-support; this is advantageous in point of simplicity and economy.

Since it is desirable that the mirror cell be a massive casting, to insure great rigidity, care has been taken, in designing it, to afford ample ventilation at the back of the mirror, so that front

and back of the latter shall be similarly exposed to temperature changes. The back of the mirror, as well as the face, is polished and silvered, in order that the two surfaces shall be similarly affected by such changes.

It is evident that the more perfect the "flotation" effect afforded by a support system, the thinner can the mirror be, in proportion to its diameter. The difficulties encountered in making very *thick* disks of glass which are homogeneous and thoroughly annealed, are so great that the problem of properly supporting comparatively thin mirrors becomes a most important one in the case of very large apertures.

YERKES OBSERVATORY,
January 1897.

Minor Contributions and Notes.

NOTE ON THE RANYARD MOUNTING FOR REFLECTING TELESCOPES.

In connection with Professor Wadsworth's description of a novel form of mounting for a reflecting telescope, devised by the late Arthur Cowper Ranyard, it may not be out of place to narrate here certain incidents connected with the last year of Mr. Ranyard's life which are intimately related to the subject of the paper.

In the autumn of 1893, while on the way through England to the Continent, Mr. Ranyard's kindly persuasions caused me to deviate from a direct path to Berlin in order to spend a few days with him in Paris. At the Paris Observatory we employed most of our time in examining the lunar and stellar photographs of the MM. Henry, the photographs of stellar spectra obtained by M. Deslandres with the remodelled reflector of Eichens, and the large scale photographs of the Moon, then but recently taken with the *equatorial coudé* by M. Loewy. The instruments themselves received no small share of our attention, and we were both particularly struck with the *equatorial coudé*, which in spite of its great size and weight is yet so perfectly within the control of the observer in his fixed position at the eyepiece.

During the following winter, which we passed in Berlin, I heard frequently from Mr. Ranyard, and it was planned that he should join our expedition to Mount Etna in the spring of 1894. This, unfortunately, his failing health did not permit him to do, but early in March, just before our departure for Italy, he paid us a visit of a few days in Berlin. He was naturally most anxious to see the Astrophysical Observatory at Potsdam, and we were fortunate in being able to spend some hours there with Professors Vogel and Scheiner. Naturally the discussion was confined for the most part to the beautiful photographs of stellar spectra obtained with the spectrograph attached to the 12-inch refractor. A careful examination of the original negatives with a microscope, coupled with a minute explanation of the details by Professor Vogel, produced a great impression upon Mr. Ranyard, and undoubtedly had much to do with his subsequent decision to take up

stellar spectroscopic work with a reflector. While thoroughly familiar with spectroscopic methods, and alive to the remarkable progress made in stellar spectroscopy since the pressure of duties at Lincoln's Inn and the demands of editorial work had diminished his activity as an investigator, his confidence in the high degree of accuracy recently attained in determinations of motion in the line of sight needed just such strengthening as the visit to Potsdam brought to it. The enthusiastic belief in the modern methods of stellar spectroscopy thus aroused was checked only by his death. It entered into a resolution formed when his illness was in its earlier stages, to remove from London in order to devote the major part of his time to astrophysical research. And it probably led him to devise the valuable form of mounting for a reflecting telescope described by Professor Wadsworth on another page. G. E. H.

A NOTE ON A NEW FORM OF FLUID PRISM.

I HAVE just received a letter from Lord Rayleigh in which he is kind enough to point out that the idea of making a fluid prism with a free liquid surface was suggested long ago by Brewster in his Treatise on Optics (§53, 455.) I am not surprised to hear that I have been anticipated, for, as I remarked in my paper, it would have been indeed surprising had so simple an idea not previously suggested itself to someone else. As however I had never seen it described, I thought it worth while to publish the description of it that I did. As there is unfortunately no copy of Brewster's work either in my own library or in that of the Observatory and as the nearest reference library is nearly eighty miles away, I have not yet had an opportunity to consult the reference myself and so am not sure but what Brewster suggested some better arrangement than mine. It is quite probable that he did, but even in the form in which I used it, its performance was most promising, and I think I may say as Poynting did with reference to the parallel plate micrometer: "Now that I have no claim to its invention I may perhaps fairly express the opinion that the instrument is of great value." F. L. O. WADSWORTH.

Reviews.

Observatory Atlas of the Moon. Lick Observatory. Published by the gift of W. W. Law, Esq., of New York City.

The first sheet of an observatory atlas of the Moon, a work which when complete, will consist of sixty or more plates, with index map, etc., has been distributed by the Lick Observatory. The scale of this important photographic map is the same as that of Beer and Mädler's chart (three Paris feet or $38^{in}.36$ to the Moon's diameter), and half that of Schmidt's chart. The plate just published shows the terminator, with the Moon near the third quarter, from the south pole to about 30° south latitude. It is reproduced from the original negative by a gelatine process, which has the advantage of giving satisfactory results at a comparatively small expense; and in a work like this, requiring more than sixty different plates for its completion, the cost of the reproductions is a consideration of no small importance.

It is interesting to compare this atlas with the one just issued by the Paris Observatory, an account of which was given in the last number of the Astrophysical Journal. If we regard the plates in these two atlases as pictures, the advantage is altogether with the Paris heliogravures; they are larger, more brilliant, more impressive. But pictorial effect is evidently no just criterion of scientific value, and if we regard the atlases from the latter standpoint, we see that each has certain advantages of its own. In the Paris photographs the enlargement has, perhaps, been pushed beyond the limit of usefulness, and it would seem that everything which appears on the plates would be shown equally well if the scale were only half as great. If this is so, the impressive appearance above referred to has been gained at the expense of handiness. Further, an examination of the Lick Observatory plate shows that brilliancy of effect has been deliberately sacrificed to secure other and more solid advantages. The printing has been carried so far that details appear in even the highest lights, with the result that, while much is shown that otherwise would have been lost in the process of reproduction, scarcely any pure white is found in the picture, and a general flatness of effect is produced. Each atlas has,

therefore, its own special value. The Paris atlas will be eminently useful for consultation in its place on the library table; the Lick Observatory atlas will find its chief use in the hand of the observer at the telescope.

No information is furnished with the plates as to the manner in which the Lick negatives are obtained, although all necessary particulars will doubtless be given with the text of the completed atlas. Professor Holden has given some details of the process in a review[1] of the Paris atlas, from which it appears that the image is directly enlarged in the telescope to a diameter of twenty-six inches, and the resulting negative is then further enlarged to the scale of the plates. The difficulties attending the first part of the process are partly obviated by the use of specially sensitive dry plates, which allow the exposure times to be reduced to ten or even to five seconds. The chief advantage of this method over that of enlarging a negative obtained at the focus is, that the coarseness of grain of the dry plate becomes relatively less important. In the Paris photographs the grain is quite conspicuous, as one would expect from the great enlargement of the original negative. A fine grain which is noticeable in the Lick Observatory plates is not, according to Professor Holden, derived from the original negative, but is introduced by the process of reproduction. It is not stated with what aperture the direct enlargements were made.

It seems to the reviewer that it would be worth while (if the attempt has not already been made) to try the old wet plate process with the modern great refractors, or at least slow and fine-grained plates such as are used for lantern transparencies. When negatives of the Moon are made on quick plates in the focus of a great telescope, the best results appear to be obtained by greatly reducing the aperture; at least this is true for the Lick telescope, which gives the sharpest definition when the aperture is stopped down to about eight inches.[2] There is little doubt that this improvement is mainly owing to the fact that with the ordinary ratio of aperture to focal length, the resolution of a photographic telescope is determined by the grain of the plate, rather than by the aperture of the objective. The telescope is unnecessarily good for the plate. Hence the aperture can be reduced without injury to the definition, and an improvement will result if the reduction is attended by gain in other directions, as for example in the diminution

[1] *Pub. A. S. P.*, No. 53, 8, 319–324, 1896.

[2] *Publications of the Lick Observatory* 3, 3.

of the effects of chromatic aberration and atmospheric disturbance. Supposing atmospheric difficulties to be avoided by choosing only the finest nights for observation, should we not expect to gain in definition by using fine-grained plates, with an aperture large enough to compensate for their greater slowness by increased brightness of the image? K.

Die Schwankungen im Wasserdampfgehalte der Atmosphäre auf Grund spectroskopischer Untersuchungen. TH. ARENDT. *Wied. Ann.*, **58**, 171–204, 1896.

IN this paper the author, a member of the staff of the Prussian Meteorological Observatory at Potsdam, gives an account of his spectroscopic investigation of the variations in the amount of aqueous vapor in the atmosphere during the latter part of the summer of 1895.

The method employed was that of estimating the intensity of the aqueous vapor lines in terms of the intensity of nearly equal metallic lines in neighboring parts of the spectrum, in a manner quite analogous to Argelander's method in stellar photometry. The third-order spectrum of a plane Rowland grating was used in connection with the large spectrometer of the Potsdam Astrophysical Observatory.

Six vapor lines were selected for observation from each of two groups of atmospheric lines, the one near C and the other near D, and respectively ten and fourteen metallic comparison lines were carefully estimated until a scale, having in the two cases ranges of 22 and 29 intensity "steps," was established. The intensity of the atmospheric lines could then at any time be estimated in steps by comparison with the metallic lines of most nearly equal intensity.

The two variable groups were treated separately in the reductions, the mean of the estimates of intensity of the six lines of each group being taken to represent the absorption in each group at the time of the observation; for which the zenith distance of the Sun and the length of path of the rays were also calculated.

In order to draw inferences as to the amount of aqueous vapor present in the air, it became necessary to reduce the observations to a uniform length of path, as they had been made at altitudes of the Sun ranging from 54° to 22°. A standard length of path of 1.50 (that for the zenith being unity) was adopted, corresponding to a zenith distance of the Sun of 48°, and corrections were applied to the observed inten-

sities to reduce them to this standard. To calculate the corrections it was necessary to test the law of increase of intensity of the lines with increase of path, which from observations of Cornu and of Müller was expected to be that of direct proportionality. This was fully confirmed by series of observations on the same day at different solar altitudes.

When the intensity of the absorption is thus reduced, and compared with the absolute humidity for each date, a close accordance is found. The author rationally considers the series of observations still too brief to justify conclusions as to the meteorological conditions in inaccessible layers of the atmosphere. He confirms the results repeatedly obtained elsewhere that the transparency of the air is greatly affected by the amount of aqueous vapor present.

As to the practical use of the method in weather prediction, Dr. Arendt gives a decidedly negative opinion. It does not follow that all methods of studying the rain-band are without value in forecasting, but it is perhaps a necessary defect of a method which always requires the spectroscope to be directed toward the Sun. For most purposes it would be desirable to measure the absorption in all azimuths, and at much lower altitudes than is possible when the Sun must be directly observed; since changes in the rain-band are of course much more pronounced when the path of the rays is long, as at altitudes of 5° or 10°. For use in connection with short forecasts, the instrument devised by C. S. Cook (*Science*, **2**, 488–491, 1883; *Am. Jour.* (3), **39**, 258–268, 1890) would seem much more suitable (to one who has used it).

The procedure adopted by Dr. Arendt appears as suitable, and the results obtained as satisfactory, as those described by Jewell in a late number of this JOURNAL (**4**, 324–342), where a photographed scale was employed for comparisons of intensity. The accuracy of Argelander's method is sufficiently established in stellar photometry to warrant its extension to spectrum lines; the exercise of judgment being required in comparisons with an artificial scale quite as much as in direct estimates.

The testimony of both observers now referred to makes it evident that there is much to be improved in methods of meteorological spectroscopy, but the papers of Arendt and Jewell may be considered as reports of progress. E. B. F.

Recent Publications.

A LIST of the titles of recent publications on astrophysical and allied subjects will be printed in each number of the ASTROPHYSICAL JOURNAL. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors. For convenience of reference, the titles are classified in thirteen sections.

1. THE SUN.

BADEN-POWELL, G. Total Eclipse of the Sun, 1896. The Novaya Zemlya Observations. Proc. R. Soc. **60**, 271, 1886.

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The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

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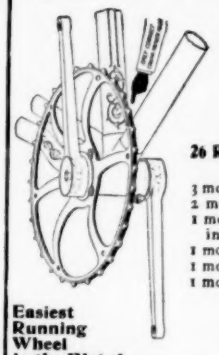

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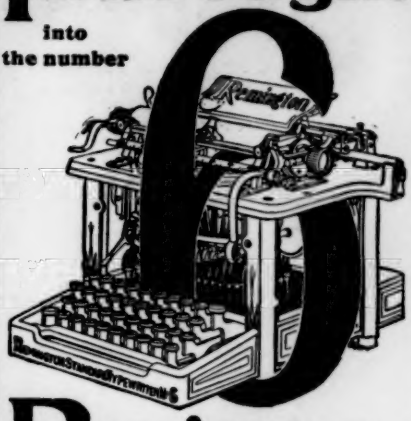

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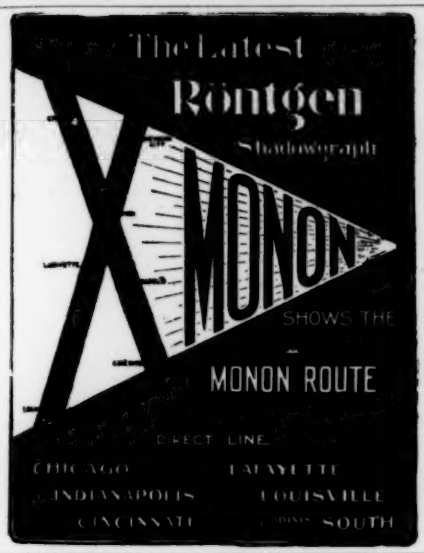

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The tuition fee for the quarter is forty dollars; for either term twenty dollars. Divinity Students are exempt from tuition fees during this quarter as during the other quarters of the year. Rooms in the college dormitories may be rented at prices varying from twenty-five to fifty dollars per quarter.

A Special *Circular of Information* for the Summer Quarter will be sent after March 1st, on application to

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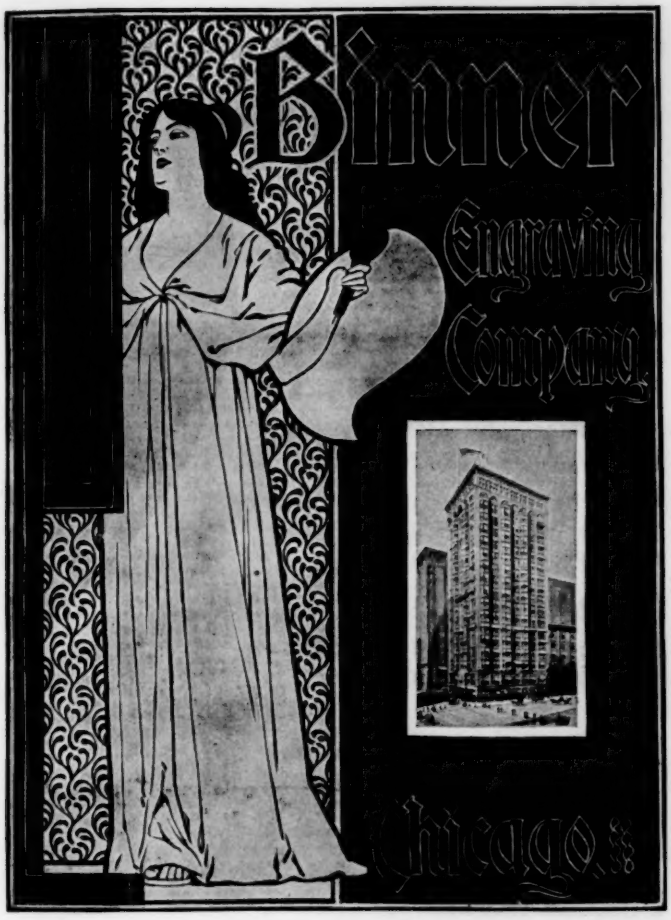

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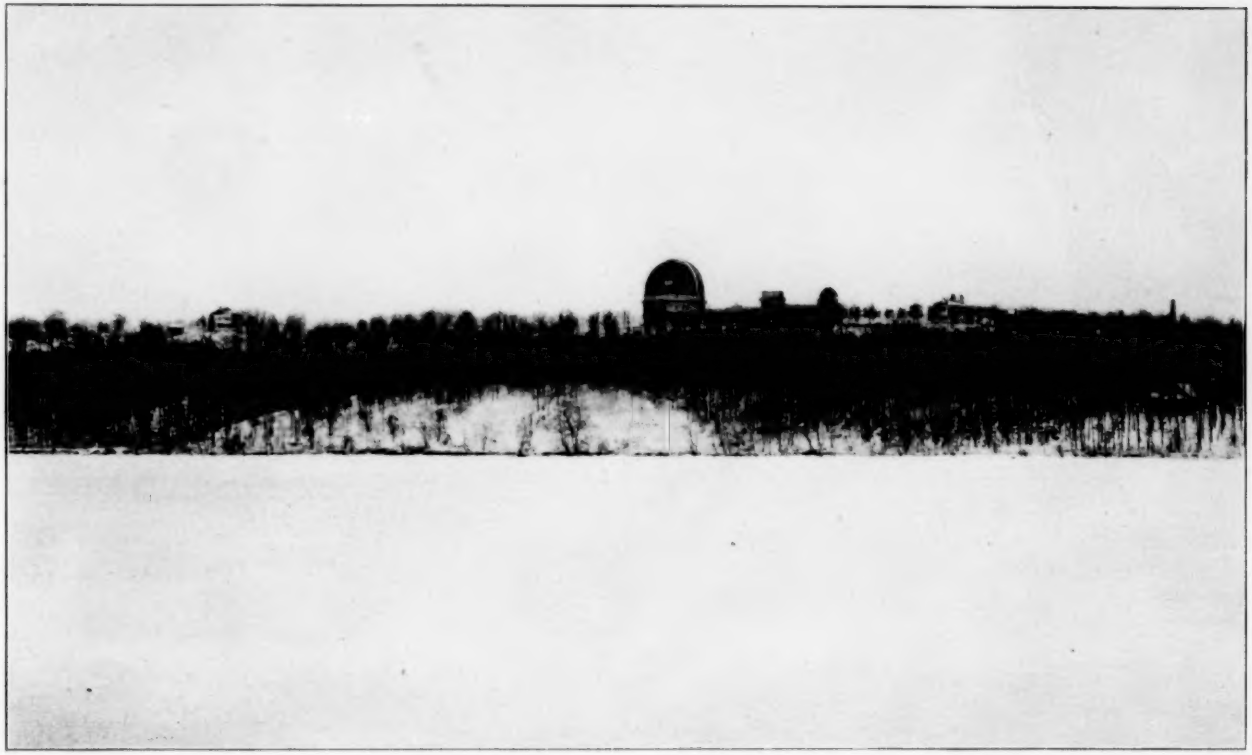

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